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VOLUME V

SEASAT ECONOMIC ASSESSMENT

COASTAL ZONES

CASE STUDY AND GENERALIZATION

NSTLS

ECON INCORPORATED

NINE HUNDRED STATE ROAD
PRINCETON, NEW JERSEY 08540
609 924-8778

May 3, 1976

Mr. Russell R. Schweickart
Code EK
NASA Headquarters
Washington, DC 20546

SUBJECT: Submission of Final SEASAT Report, "Volume V, SEASAT Economic Assessment Coastal Zones Case Study and Generalization"

Dear Rusty,

Enclosed are ten (10) final hard copies and one (1) reproducible final copy of the report, "Volume V, SEASAT Economic Assessment Coastal Zones Case Study and Generalization." This report is submitted in fulfillment of Task B.2 of Contract NASW-2558 dated April 3, 1975.

This final report is submitted for your review. We would appreciate the opportunity to discuss the results of the study with interested members of the Office of Applications staff at your convenience.

Best regards,

B.P. Miller

B.P. Miller
Vice President

BPM/jwt

Encs. 11

cc: F. Waller

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Report No. 75-125-5B
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FINAL

VOLUME V

SEASAT ECONOMIC ASSESSMENT

COASTAL ZONES

CASE STUDY AND GENERALIZATION

Prepared for

National Aeronautics and Space Administration
Washington, D.C.

Contract No. NASW-2558

August 31, 1975

Note of Transmittal

The SEASAT Economic Assessment was performed for the Special Programs Division, Office of Applications, National Aeronautics and Space Administration, under Contract NASW-2558. The work described in this report began in February 1974 and was completed in August 1975.

The economic studies were performed by a team consisting of Battelle Memorial Institute; the Canada Centre for Remote Sensing; ECON, Inc.; the Jet Propulsion Laboratory; the Ocean Data Systems, Inc. ECON, Inc. was responsible for the planning and management of the economic studies and for the development of the models used in the generalization of the results.

This volume presents a case study and its generalization concerning the economic benefits of the improved forecasting of weather and ocean conditions to coastal zones.

The coastal zones case studies were performed by Battelle Memorial Institute and Ocean Data Systems, Inc. C.W. Hamilton managed the case study performed by Battelle. P. Wolff managed the case study performed by Ocean Data Systems, Inc. The integration and generalization of the case study results were performed by K. Hicks of ECON, Inc.

The SEASAT Users Working Group (now Ocean Dynamics Subcommittee), chaired by J. Apel of the National Oceanographic and Atmospheric Administration, served as a valuable source of information and a forum for the review of these studies. S.W. McCandless, the SEASAT Program Manager, coordinated the activities of the many organizations that participated in these studies into the effective team that obtained the results described in this report.

B.P. Miller

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1. OVERVIEW OF THE ASSESSMENT

This report, consisting of ten volumes, represents the results of the SEASAT Economic Assessment, as completed through August 31, 1975. The individual volumes in this report are:

Volume I - Summary and Conclusions
Volume II - The SEASAT System Description and Performance
Volume III - Offshore Oil and Natural Gas Industry - Case Study and Generalization
Volume IV - Ocean Mining - Case Study and Generalization
Volume V - Coastal Zones - Case Study and Generalization
Volume VI - Arctic Operations - Case Study and Generalization
Volume VII - Marine Transportation - Case Study and Generalization
Volume VIII - Ocean Fishing - Case Study and Generalization
Volume IX - Ports and Harbors - Case Study and Generalization
Volume X - A Program for the Evaluation of Operational SEASAT System Costs.

Each volume is self-contained and fully documents the results in the study area corresponding to the title. Table 1.1 describes the content of each volume to aid readers in the selection of material that is of specific interest.

The SEASAT Economic Assessment began during Fiscal Year 1975. The objectives of the preliminary economic assessment, conducted during Fiscal Year 1975, were to identify the uses and users of the data that could be produced by an operational SEASAT system and to provide preliminary estimates of the benefits produced by the applications of this

Table 1.1: Content and Organization of the Final Report

Volume No.	Title	Content
I	Summary and Conclusions	A summary of benefits and costs, and a statement of the major findings of the assessment.
II	The SEASAT System Description and Performance	A discussion of user requirements, and the system concepts to satisfy these requirements are presented along with a preliminary analysis of the costs of those systems. A description of the plan for the SEASAT data utility studies and a discussion of the preliminary results of the simulation experiments conducted with the objective of quantifying the effects of SEASAT data on numerical forecasting.
III	Offshore Oil and Natural Gas Industry-Case Study and Generalization	The results of case studies which investigate the effects of forecast accuracy on offshore operations in the North Sea, the Celtic Sea, and the Gulf of Mexico are reported. A methodology for generalizing the results to other geographic regions of offshore oil and natural gas exploration and development is described along with an estimate of the world-wide benefits.
IV	Ocean Mining - Case Study and Generalization	The results of a study of the weather sensitive features of the near shore and deep water ocean mining industries are described. Problems with the evaluation of economic benefits for the deep water ocean mining industry are attributed to the relative immaturity and highly proprietary nature of the industry.

Table 1.1. Content and Organization of the Final Report
(continued)

Volume No.	Title	Content
V	Coastal Zones - Case Study and Generalization	The study and generalization deal with the economic losses sustained in the U.S. coastal zones for the purpose of quantitatively establishing economic benefits as a consequence of improving the predictive quality of destructive phenomena in U.S coastal zones. Improved prediction of hurricane landfall and improved experimental knowledge of hurricane seeding are discussed.
VI	Arctic Operations - Case Study and Generalization	The hypothetical development and transportation of Arctic oil and other resources by ice breaking super tanker to the continental East Coast are discussed. SEASAT data will contribute to a more effective transportation operation through the Arctic ice by reducing transportation costs as a consequence of reduced transit time per voyage.
VII	Marine Transportation-Case Study and Generalization	A discussion of the case studies of the potential use of SEASAT ocean condition data in the improved routing of dry cargo ships and tankers. Resulting forecasts could be useful in routing ships around storms, thereby reducing adverse weather damage, time loss, related operations costs, and occasional catastrophic losses.
VIII	Ocean Fishing - Case Study and Generalization	The potential application of SEASAT data with regard to ocean fisheries is discussed in this case study. Tracking fish populations, indirect assistance in forecasting expected populations and assistance to fishing fleets in avoiding costs incurred due to adverse weather through improved ocean conditions forecasts were investigated.
IX	Ports and Harbors - Case Study and Generalization	The case study and generalization quantify benefits made possible through improved weather forecasting resulting from the integration of SEASAT data into local weather forecasts. The major source of avoidable economic losses from inadequate weather forecasting data was shown to be dependent on local precipitation forecasting.
X	A Program for the Evaluation of Operational SEASAT System Costs	A discussion of the SATIL 2 Program which was developed to assist in the evaluation of the costs of operational SEASAT system alternatives. SATIL 2 enables the assessment of the effects of operational requirements, reliability, and time-phased costs of alternative approaches.

data.* The preliminary economic assessment identified large potential benefits from the use of SEASAT-produced data in the areas of Arctic operations, marine transportation, and offshore oil and natural gas exploration and development.

During Fiscal Year 1976, the effort was directed toward the confirmation of the benefit estimates in the three previously identified major areas of use of SEASAT data, as well as the estimation of benefits in additional application areas. The confirmation of the benefit estimates in the three major areas of application was accomplished by increasing both the extent of user involvement and the depth of each of the studies. Upon completion of this process of estimation, we have concluded that substantial, firm benefits from the use of operational SEASAT data can be obtained in areas that are extensions of current operations such as marine transportation and offshore oil and natural gas exploration and development. Very large potential benefits from the use of SEASAT data are possible in an area of operations that is now in the planning or conceptual stage, namely the transportation of oil, natural gas, and other resources by surface ship in the Arctic regions. In this case, the benefits are dependent upon the rate of development of the resources that are believed to be in the Arctic regions, and also dependent upon the choice of surface transportation over pipelines as the means of moving these resources to the lower

*SEASAT Economic Assessment, ECON, Inc., October 1974.

latitudes. Our studies have also identified that large potential benefits may be possible from the use of SEASAT data in support of ocean fishing operations. However, in this case, the size of the sustainable yield of the ocean remains an unanswered question; thus, a conservative viewpoint concerning the size of the benefit should be adopted until the process of biological replenishment is more completely understood.

With the completion of this second year of the SEASAT Economic Assessment, we conclude that the cumulative gross benefits that may be obtained through the use of data from an operational SEASAT system, to provide improved ocean condition and weather forecasts is in the range of $859 million to $2,709 million ($1975 at a 10 percent discount rate) from civilian activities. These are gross benefits that are attributable exclusively to the use of SEASAT data products and do not include potential benefits from other possible sources of weather and ocean forecasting that may occur in the same period of time. The economic benefits to U.S. military activities from an operational SEASAT system are not included in these estimates. A separate study of U.S. Navy applications has been conducted under the sponsorship of the Navy Environmental Remote Sensing Coordinating and Advisory Committee. The purpose of this Navy study was to determine the stringency of satellite oceanographic measurements necessary to achieve improvements in

military mission effectiveness in areas where benefits are known to exist.* It is currently planned that the Navy will use SEASAT-A data to quantify benefits in military applications areas. A one-time military benefit of approximately $30 million will be obtained by SEASAT-A, by providing a measurement capability in support of the Department of Defense Mapping, Charting and Geodesy Program.

Preliminary estimates have been made of the costs of an operational SEASAT program that would be capable of producing the data needed to obtain these benefits. The hypothetical operational program used to model the costs of an operational SEASAT system includes SEASAT-A, followed by a number of developmental and operational demonstration flights, with full operational capability commencing in 1985. The cost of the operational SEASAT system through 2000 is estimated to be about $753 million ($1975, 0 percent discount rate) which is the equivalent of $272 million ($1975) at a 10 percent discount rate. It should be noted that this cost does not include the costs of the program's unique ground data handling equipment needed to process, disseminate or utilize the information produced from SEASAT data. Figures 1.1 and 1.2 illustrate the net cumulative SEASAT exclusive benefit stream (benefits less costs) as a

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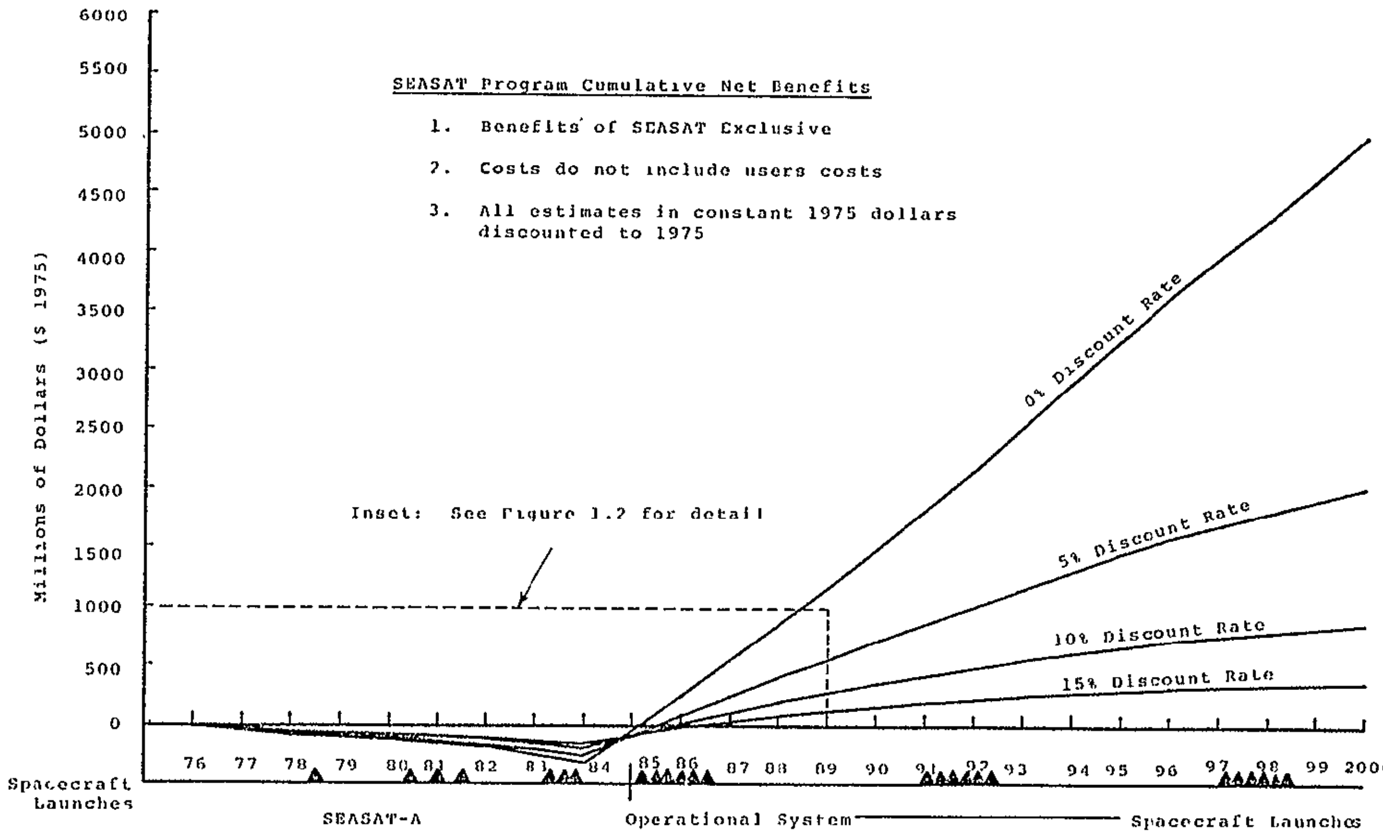
*"Specifications of Stringency of Satellite Oceanographic Measurements for Improvement of Navy Mission Effectiveness." (Draft Report.) Navy Remote Sensing Coordinating and Advisory Committee, May 1975.



Costs*	19	49	78	100	123	151	184	239	307	352	368	373	375	393	437	503	546	566	568	587	629	695	738	753
Benefits*										311	622	933	1244	1555	1937	2319	2701	3083	3465	384	4229	4611	537	5757

*Cumulative Costs and Benefits at 0% Discount Rate (millions, $ 1975)

Figure 1.1 SEASAT Net Benefits, 1975-2000

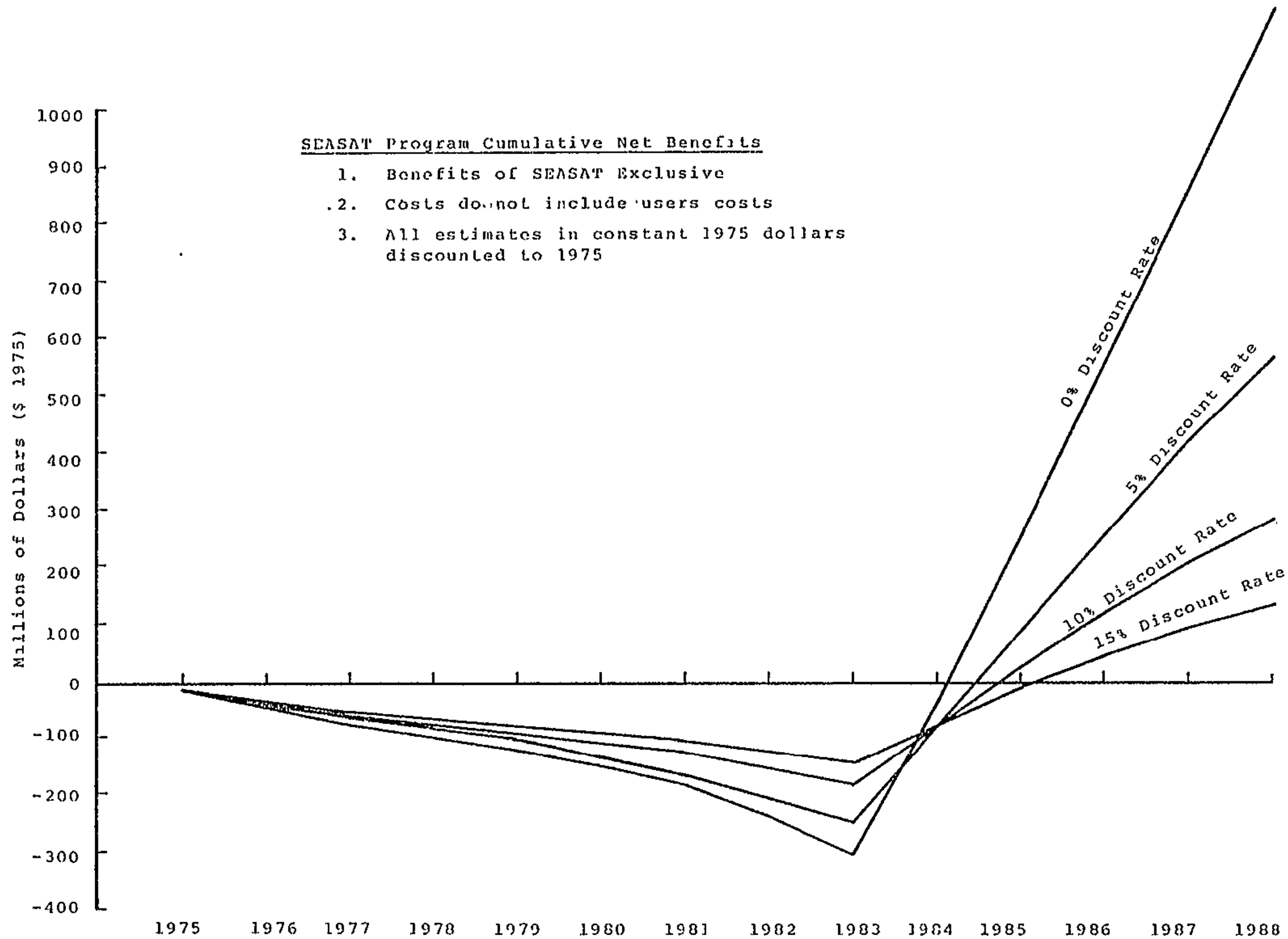


Figure 1.2 SEASAT Net Benefits, Inset

function of the discount rate.

This volume describes the results of the case studies and generalization of the economic benefits of improved forecasts of weather and ocean conditions to coastal zone regions.

2. CASE STUDY AND GENERALIZATION OF COASTAL ZONE ECONOMIC BENEFITS

2.1 Introduction

The coastal region of the United States, its coastal waters, beaches and some distance inland, is frequently subjected to destructive forces as a result of the natural interactive influences of sea conditions and weather.

This coastal region is the site of many national industrial and commercial activities as well as the location of residential population, both permanent and transient, together with substantial recreational facilities. The destructive forces generated can produce quite extensive amounts of property damage and losses of life and livelihood.

The historical occurrence of these destructive coastal zone phenomena is reasonably well documented and has led to the introduction of construction practices which attempt to minimize the economic and human losses that can be produced. Concurrently, national emergency programs have been organized which attempt to convince the population that evacuation would be prudent and which also provide relief to those that suffer the consequences of the destructive phenomena.

It is generally clear that today nothing can be done to diminish either the power of the destructive forces

generated or to divert the destructive process away from the coastal zone, although hurricane seeding is being experimentally explored for both these purposes.

However, it is reasonably contended that if reliable, accurate and timely prediction of the time, location and duration of occurrence of these destructive coastal zone phenomena could be made then the consequent economic losses could be reduced. In theory, with perfect predictive ability and the means to adequately disseminate the prediction conditions, that is within a totally credible prediction system, every conceivable action to protect life and property could be introduced and all programs for relief following the destructive occurrence could be mobilized with maximum effectiveness. Thus would perfect prediction provide a systematic means of reducing economic losses as a consequence of coastal zone destructive phenomena. These reduced economic losses will be called avoidable losses. To the extent that there is imperfection in the procedure of prediction, there will be reluctance to initiate actions to contend with the destructive force possibility and so will the effectiveness of mobilization of relief be diminished. Imperfect prediction then implies that certain avoidable losses will be sustained and also that certain avoidable losses will actually be avoided.

SEASAT, as an operational entity, will provide sea condition and weather phenomena data, not previously available in terms of scope, quality and frequency of observation. This data, introduced as input into appropriate phenomenological and numerical computer models, will to some degree improve the capability of prediction that is available. The SEASAT data availability can then be visualized as being responsible for the actual avoidance of some apparent avoidable economic losses to the United States coastal zone region. These incremental avoidable economic losses, assumed actually to be avoided, are the direct economic benefit generated by SEASAT.

The procedure of prediction is of a complexity which obscures the clarity of SEASAT's actual data contribution so that economic benefits to prediction improvement in general are more simple to visualize.

This case study and its generalization seek to quantitatively establish economic benefits and SEASAT economic benefits as a consequence of improving the predictive quality of occurrence of coastal zone destructive phenomena.

2.2 Summary

The coastal zones of the United States; Atlantic, Gulf of Mexico, Pacific, Alaska and Hawaii, have been evaluated for the economic losses they sustain from naturally occurring phenomena which destroy both life and property.

These phenomena are the result of oceanographic and meteorological processes which give rise to unusual and excessive winds, rainfall and sea conditions, which then in a variety of ways produce the economic losses.

It is reasoned that through accurate modelling of the phenomena in question, with appropriate and extensive observational data as input to the models, such as SEASAT can provide, prediction of the time, place and duration of the occurrence of the phenomena and their associated destructive characteristics could be improved. This improved prediction capability would then allow some economic losses to be avoided, if appropriate precautions are implemented. Economic losses that can be avoided are termed benefits.

In addition, specifically for hurricanes, and therefore, for the Atlantic and Gulf coastal zones, error in prediction of the landfall of a hurricane results in incremental precautionary expenditures for prevention of damage and loss of life. Improvement in landfall prediction through more efficient modelling and input data will reduce the landfall error and diminish the incremental precautionary expenditures. This reduction is an additional benefit.

Finally, a possibility exists that the destructive force of a hurricane can be diminished by appropriate seeding during the hurricane process. It is assumed that the seeding effect diminishes the peak winds associated with the hurricane.

Hurricane damage reduction is considered only as wind force reduction, however, and not from hurricane induced storm surge modification. It should be noted that the potential effects of seeding are inadequately understood at the present time. For example, if the reduction of wind forces produced by seeding is accompanied by changes in precipitation patterns, it is possible that a disbenefit could also be incurred. Effective seeding, essentially an experimental technique, can only be developed from improved hurricane dynamic modelling and an adequacy of real data input.

The benefit ranges for each of the three cited sources or origins for the year 1985 are shown in Table 2.1. The 1985 benefits are assumed to be representative of the annual benefits for each year from 1985 to 2000. They depend on data provided by a wide variety of sources. It has been estimated that SEASAT may be considered to be the source of 30 percent of these benefits through the unique and extensive data it will provide in its operational configuration. Benefits are integrated and discounted for the time interval from 1985 to the time horizon of the study, 2000. The integrated benefits are shown in Table 2.2.

2.3 Conclusions

As the historical data available attests, there are substantial estimated annual economic losses in property and in life from the natural phenomena producing destructive forces in the nation's coastal zones. Most of these phenomena develop

Table 2.1 1985 Coastal Zone Benefits		
Benefit Origin	Estimated Annual Benefit Range ($ million)	
	Minimum	Maximum
Improved prediction of destructive phenomena *	53	306
Improved prediction of Hurricane landfall	1.4	28
Seeding of landfall hurricanes	2.9	63
Total benefit	4	91

*Benefits not included in totals because physical or operational prevention costs are not estimatable.

Table 2.2 Integrated Coastal Zone Benefits 1985-2000				
Discount rate %	0	5	10	15
Benefits from all data sources ($ millions)	64-1456	27-610	12-274	6-134
Benefits exclusive to SEASAT data ($ millions)	16-432	7-181	3-81	1-40

under the influence of reasonably well understood meteorological and oceanographic conditions. The economic losses that they produce, however, result from an inability to predict (or control) the magnitudes of the destructive characteristics that will be produced in the coastal waters and in the coastal zone land regions.

Computer models and simulations of these natural phenomena, their processes of formation and their characteristics of propagation are being developed but the accuracy of their outputs is constrained largely by the absence of large-scale and high quality data for pertinent parameters, by which the models are initialized.

The large scale nature of the development of the destructive phenomena and their total process of formation and disintegration makes remotely sensed satellite data of great apparent significance to their understanding and modelling.

However in a strict sense, at this time, the precise sensitivity of prediction to the improved data gathering capabilities of a satellite is not known. Though there is an apparent basis for improvement, it is not yet quantifiable. Economic losses suffered can be regarded as a mixture of avoidable and nonavoidable losses. Losses which are avoidable are those assumed to be excludable if appropriate forecast knowledge is available. Forecast knowledge implies correctly identifying the totality of interaction of natural phenomena with the coastal zone region. Then it is assumed

that preventative measures can be established by which the losses are avoided. If the required preventative measures are only procedural, then it is clear that the avoidable losses can become benefits to the improved prediction resulting from the data made available. That is, if only a procedural change is required, expenditure for prevention is minimal. On the other hand if the preventative measures needed involve operations or physical structures to be constructed and maintained then the relationship between avoidable losses and benefits must be modified by the cost of prevention.

In this case study, losses result in general from abnormal localized occurrences of wind, rain, sea levels and breakers. It is difficult to realistically determine the true composition of avoidable losses without extensive statistical knowledge of phenomena characteristics and cost of prevention relative to benefits. The benefits developed in this case study and generalization are therefore based largely on qualitative acceptance that the data will generate improvement in prediction, and judgmental estimates of the expected mangitudes of the improvement. This is apparent in the ranges of minimum to maximum benefit.

2.4 The Case Study, Results and Generalizations

Coastal zone economic losses are the result of observable phenomena resulting from abnormal wind and sea

conditions, generally in combination, and frequently accompanied by heavy rainfall.

The coastal zone waters are violently disturbed, their disturbance penetrating into ports, harbors and marinas, breakers and surf, through their pounding action damage or destroy formations and structures installed to contain the sea and the sea invades the coastal land surface. If a particular disturbance coincides with normal very high tides, then the sea invasion of the land is very extensive.

For the case study, the general meteorological and oceanographic observable phenomena are identified as well as the ordered significance of these phenomena with respect to the various United States coastal regions, and the production of economic losses there. Data is assembled from which estimates of coastal zone damages have been made.

Since avoidable economic loss reduction is the result of prediction of the occurrence of abnormal phenomena, the data for predictive modelling is discussed as is the significance of SEASAT's input data.

Hurricanes as coastal zone economic loss producing phenomena are discussed in depth to identify the significance of hurricane landfall prediction. Both the minimization of losses to property and life and the minimization of unnecessary expense for emergency procedures are discussed. In addition, hurricane seeding is discussed as a potential moderating mechanism of the hurricane's force.

2.4.1 Coastal Zone Economic Loss Producing Natural Phenomena

The principal oceanographic and meteorological phenomena whose occurrence produces economic losses both avoidable and unavoidable in the coastal zones are typically as follows:

- Storm surges from tropical storms and hurricanes
- Storm surges from extratropical storms
- High winds and wind-driven waves associated with tropical storms and hurricanes
- High winds and wind-driven waves associated with extratropical storms and severe frontal systems
- High surf resulting from long-period swells, generated by distant storms
- Violent local winds associated with isolated squall lines or severe thunderstorms
- Tsunamis (tidal waves) caused by earthquakes.

The storm surge raises the level of the sea above its normal tidal rise perhaps as much as 30 feet and is associated with wind and low pressure drop. The high surf results from substantial sea swells which produce very large breakers upon shoaling in shallow waters. Tsunamis are seismically produced sea waves.

Natural phenomena that cause economic loss vary in importance with the United States coastal zone region. The predominant loss producing phenomena around the coast of the continental United States, Alaska and Hawaii are identified in

Figure 2.1. The predominance is established from historical observations.

Each coastal region is menaced by different naturally occurring meteorological phenomena.

The Atlantic Coastal Zone is under the strong influence of the Bermuda subtropical high pressure center, the North American land mass upstream and the warm Gulf Stream immediately offshore.

The Gulf of Mexico Coastal Zone is under the strong influence of the interaction between the uniformly warm Gulf waters and cold air outbreaks from the North American continent.

The Pacific Coastal Zone is under the strong influence of the oceanic moisture upstream, the cold coastal upwellings and the position and intensity of the Pacific subtropical high-pressure center and the Aleutian low pressure center.

The Alaskan Coastal Zone is under the strong influence of extratropical storms which move into the Gulf of Alaska from the west southwest.

The Hawaiian Coastal Zone is influenced by hurricanes originating off Central America; semitropical Kona storms and during the wintertime by long-period swells, initiated by storms between Kamchatka and the Aleutian Islands.

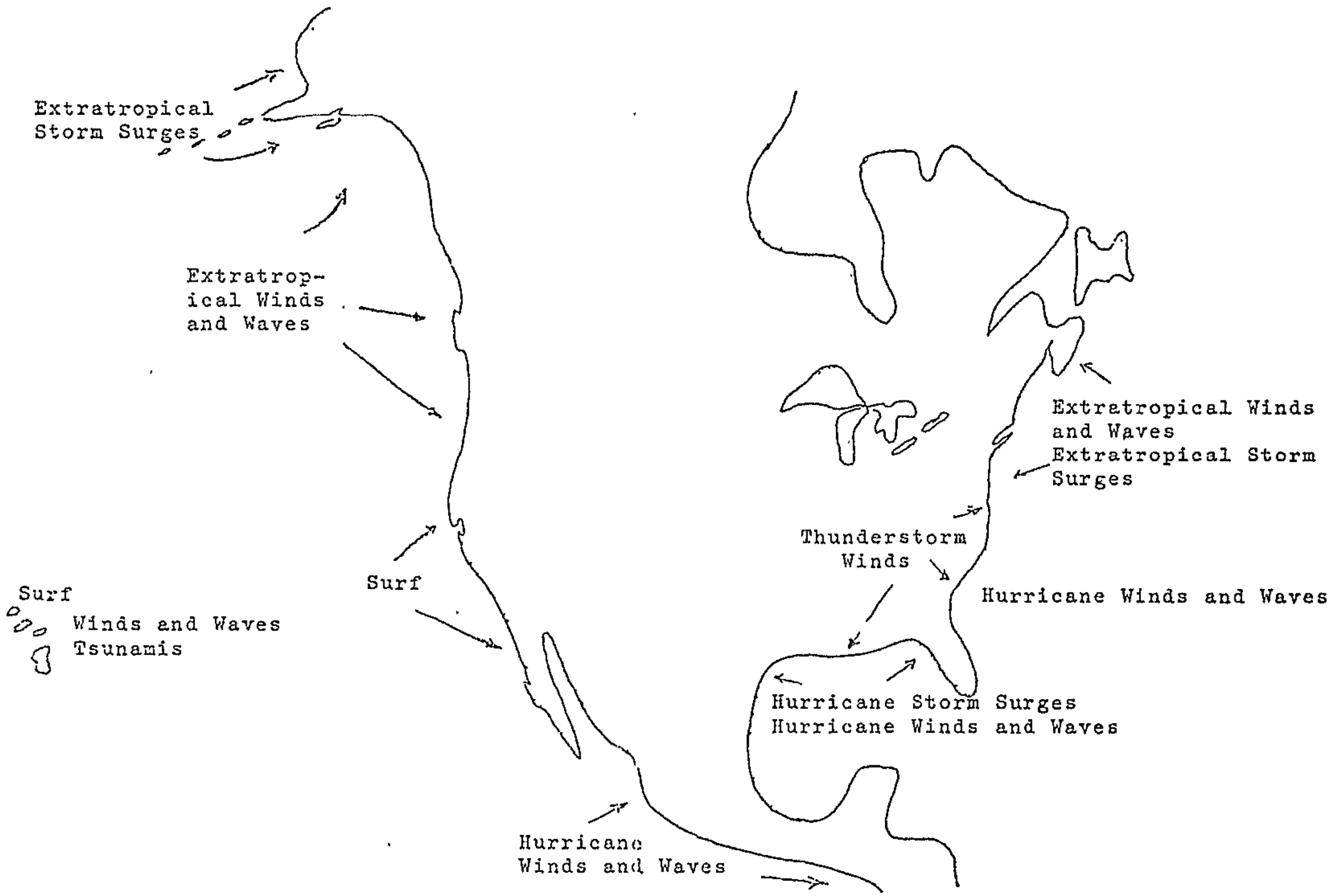


Figure 2.1 Predominant Coastal Zone Natural Phenomena Producing Economic Losses

2.4.2 The Relative Economic Importance of the Loss Producing Natural Phenomena

Table 2.3 identifies the relative economic importance of the principal natural phenomena to different coastal zones. As a result of these various phenomena and their phenomenology, the potential exists for reducing avoidable economic loss through prediction of events and dissemination of the prediction data.

This historical documentation and the precision of economic loss estimates of events associated with the identifiable predominant natural phenomena is far from complete. The next section will discuss the data available and attempt to quantify the magnitudes of the losses associated with various phenomena.

2.4.3 Coastal Zone Economic Loss Data

Two distinct sets of data descriptive of coastal zone economic losses were sought. One set would be useful in establishing the losses resulting from the various destructive natural phenomena, the other would provide loss relationships that would arise as a consequence of the destructive natural phenomena being inadequately predicted. The latter data is then concerned with establishing losses associated with warning, in particular with respect to hurricane warning.

2.4.3.1 Economic Losses Resulting from Destructive Natural Phenomena in the Coastal Zones of the United States

Because of the scope involved, neither a comprehensive survey nor an economic analysis of coastal zone losses

Table 2.3 Relative Economic Loss Importance of Naturally Occurring Phenomena in Coastal Zone Regions

Order	Cause	Remarks
	ATLANTIC	
1.	Hurricane Storm Surges	Entire Atlantic Coast is vulnerable
2.	High Winds and Wind Waves	Primarily tropical origin extratropical North of Hattaras
3.	Severe Thunderstorm Winds	Chesapeake Bay notorious for number of boats swamped
4.	Extratropical Storm Surges	Primarily North of Hattaras
5.	High Surf	Relatively rare from extratropical storms - primarily from hurricane
5.	Tsunamis	Extremely rare, but possible
	GULF OF MEXICO	
1.	Hurricane Storm Surges	Tallahassee to Corpus Christi
2.	High Winds and Wind Waves	Primarily with hurricanes but occasionally with cold fronts
3.	Severe Thunderstorm Winds	Entire coastal zone vulnerable
4.	High Surf	Primarily from hurricanes
5.	Extratropical Storm Surges	Rare
5.	Tsunamis	Extremely rare
	PACIFIC	
1.	High Winds and Wind Waves	Extratropical origin - both storm centers and cold fronts
2.	High Surf	From distant Pacific storms. California suffers most damage.
3.	Tsunamis	Aleutian, Kamchatka and South Pacific quakes
4.	Extratropical Storm Surges	Quite rare because of bathymetry
5.	Severe Thunderstorm Winds	Rare compared to Atlantic and Gulf Coasts
6.	Tropical Storm Surge	Essentially no threat
	ALASKA	
1.	High Winds and Wind Waves	Extratropical storm origin
2.	Extratropical Storm Surges	Gulf of Alaska and Bering Sea Coasts in areas where bathymetry is favorable
3.	High Surf	All coasts where bathymetry is favorable; extratropical origin
4.	Tsunamis	Quakes in both Northern and Southern Pacific
5.	Severe Thunderstorm Winds	Very rare
6.	Tropical Storm Surges	No threat
	HAWAII	
1.	High Surf	North coasts; extratropical origin
2.	High Winds and Wind Waves	Kona storms and cold fronts; very rarely from tropical storm or hurricane
3.	Tsunamis	Quakes in both Northern and Southern Pacific
4.	Severe Thunderstorm Winds	Comparatively rare
5.	Storm Surges	Little or no threat

during the past century was undertaken. Statistical data was found, however, relating to four principal natural phenomena which produce coastal zone damage. This data is located in Appendix A.1, Tropical Cyclones; Appendix A.2, Extratropical Storms; Appendix A.3, Tsunamis; Appendix A.4, Surf and Appendix A.5, Coastal Monterey, California, USCG Calls for Assistance.

From this data Table 2.4 was derived, showing annual economic loss estimates in the United States coastal zones.

For tropical cyclones, the average loss of life from 1964 to 1974, from Appendix A.1, is 55 and the average damage category is slightly greater than number 8 which ranges from $50 million to $500 million.

The Appendix also shows that an average of 3.6 tropical storms reach the Atlantic or Gulf coast land boundaries each year, and that an average of 1.8 storms per year strike the coast with winds of hurricane intensity (65 knots or greater). In the United States, an average of 67 lives are lost each year with a maximum of 600 in one year (1938). The loss of life outside the United States is much greater.

During six of the years, the total property loss exceeded $500,000,000 and during twelve years the losses were between $50,000,000 and $500,000,000. Only three of the years since 1941 had losses under $5,000,000. The damage total in Louisiana from Hurricane Betsy (1965) was estimated to be $1.2 billion.

Table 2.4 Annual Economic Loss Estimates in Coastal Zones of U. S.

Origin	Loss of Life	Property Losses ($ millions)		
		Low	Average	High
Tropical Cyclones (1964-1974)	55	50	200	500
Extratropical Storms	unreliable	75	100	200
Tsunamis	5	.5	1	1.5
Surf	unreliable	20	26	50
Total		145.5	327	751.5

The data on extratropical storms, Appendix A.2, is not as clearly documented as is the data for tropical cyclones, because these storms are usually much less spectacular and less concentrated.

The literature contains accounts of extratropical superstorms, however. The famous November storm of 1913 cost 200 lives and $2,000,000 damage on the Great Lakes and $70,000,000 overall damage to the Eastern United States. The great November storm of 1950 took 160 lives and caused damages exceeding $70,000,000. The Veterans Day storm of 1968 cost 28 lives and $20,000,000 in insurable fixed losses not including damages to boats and fishing gear. (Lobster trap losses were estimated at 75 percent.) While these superstorms are most spectacular and best remembered, countless smaller extratropical storms exact a very great toll each year.

The figures quoted in Table 2.4, for extratropical storms are a judgmental estimate of the combination of extratropical superstorms and normal storms.

From Appendix A.3 the damage caused by tsunamis has been estimated, based on averages of the numbers provided by the quoted references, this being the best estimate possible with the data available. The data relating to surf damage in Appendix A.4 is not comprehensive and reports damage estimates ranging from \$1-\$1.5 million to \$125 million. The annual estimates for surf damage in Table 2.4 are judgmental.

Overall, from these four principal natural origins the United States coastal zones are estimated to undergo annual losses ranging from \$145 million to \$752 million. The estimates are considered to be conservative yet there is a great deal of difficulty in finding precise values to assign to losses resulting from storm damage in general.

2.4.4 Economic Losses Which are a Consequence of Destructive Natural Phenomena in the Coastal Zones of the United States

Hurricanes are quite significant natural phenomena which produce considerable coastal zone damage on the Gulf and East coasts of the United States. The coincidence of substantial winds, torrential rain and the high seawater levels or storm surge is responsible for a wide variety of destruction and damage. The hurricane disaster potential is summarized in Appendix A.6, and the estimated economic losses they produce is substantial.

The process of formation of a hurricane is a lengthy one and can be observed at sea. Since their destructive potential is well known, a hurricane watch is established by the National Weather Service. The objective of the watch is tó generate appropriate forewarning of the expected interaction of the hurricane with the United States coastal zones. Precautions can then be taken in the interaction region which will effect reduction of loss of life, loss of property and damage to property.

Currently, a warning provides 12 hours of daylight preparation time; it is issued 15-18 hours before estimated landfall and the warning extends over 200-300 miles of coastal region. On the average, hurricane force winds extend over a distance of 50 miles from the storm center, but because the average error in a 24-hour forecast is about 100 miles, the current warning distance is necessary to accomodate the objectives of warning.

If the objectives of warning are to be successfully achieved, within the warning region specified the population and its services must disrupt their normal activities and engage in the implementation of precautionary actions. These actions involve expenditures of many kinds. To the extent that our current knowledge and capabilities result in a larger warned region than is necessary, so must expenditures be incurred by the national population that are not necessary. In addition, skepticism of the warning quality results in a

lack of precautionary measures by the population which can possibly result in damage being produced needlessly by a hurricane. Together the lack of predictive quality in the hurricane's interaction with the coastal zone can be responsible directly and indirectly for economic losses that are avoidable.

2.4.4.1 Case Study Results

Early in the case study it was decided to attempt to verify hurricane precautionary costs found in the literature through local studies to be carried out in selected geographical areas. In choosing the areas, it was desirable that they have a history of having been struck relatively frequently by hurricanes and that their damage potential be reasonably high. Figure 2.2 shows coastal areas that were struck by ten or more hurricanes in the years from 1886 to 1970 [1]. Figure 2.3 presents the potential for damage along the coast in terms of percent of residential property damage expected per year due to wind and rain damage from tropical storms and hurricanes [17]. On the basis of this information, the areas shown in Table 2.5 were chosen as study candidates.

Figure 2.2 Sections of Coast Experiencing More Than Ten Hurricanes From 1886-1970

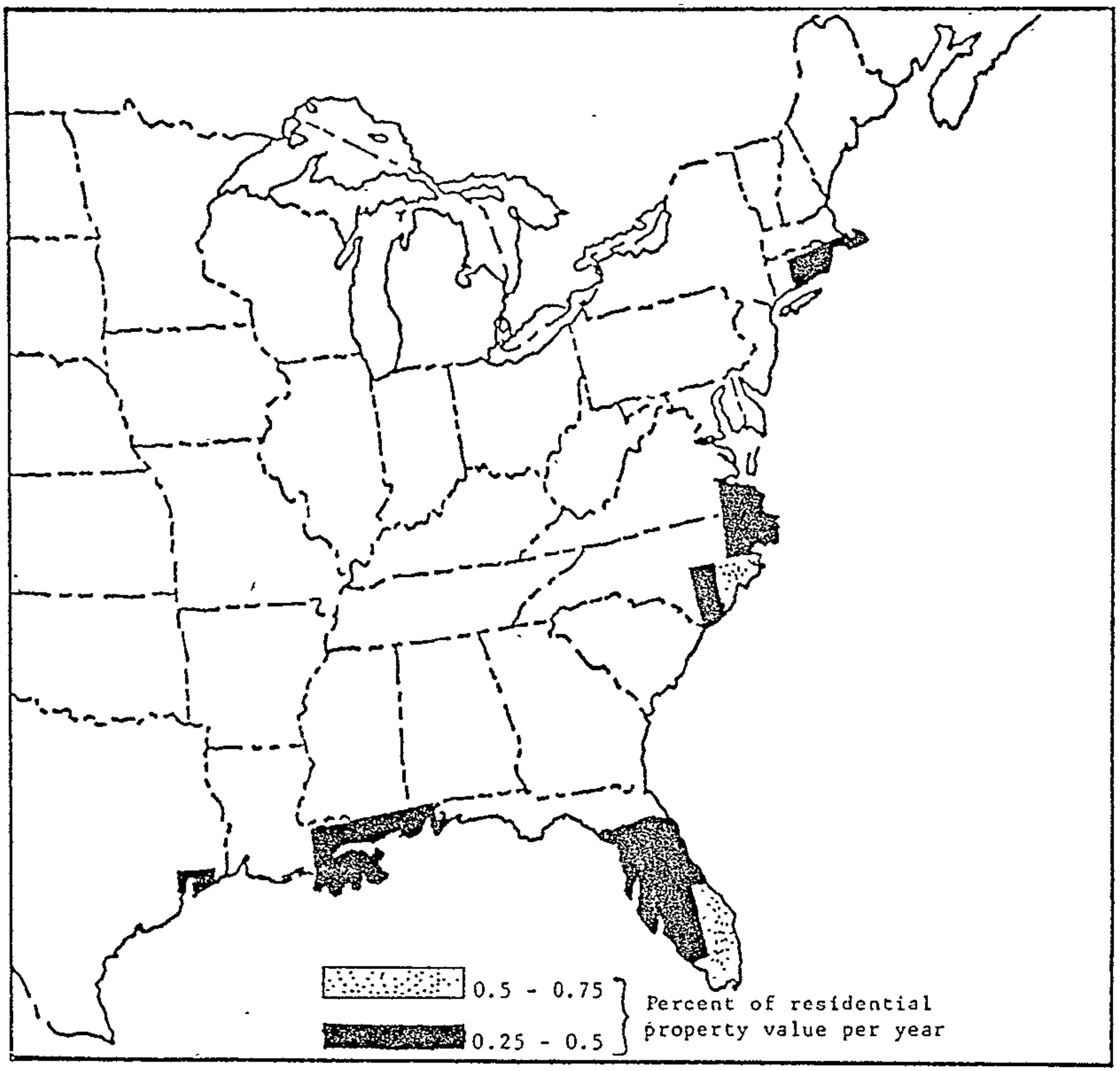


Figure 2.3 Average Annual Risk of Hurricane and Tropical Storm Damage

Table 2.5 Locations Chosen for Local Studies

	Hurricane Frequency	Loss Potential	Regional Character
Dade and Broward Counties, Florida	.15	High	Metropolitan, Residential, Tourist
New Orleans, Eastern Louisiana, and Mississippi Coast	.10	High	Metropolitan, Residential, Industrial
North Carolina Coast between Wilmington and north boundary	.11	Moderate	Small towns, Residential, Coastal plains

Dade County, Florida,* was the first case study to be investigated. Interviews were conducted with the following persons:

1. Manager of the Dade County Metro Government
2. Director of Dade County Civil Defense
3. Coordinator of Civil Defense for Dade, Broward and Monroe Counties
4. Head of General Services Administration for Dade County; also serving as Director of Dade County Office of Emergency Preparedness
5. Director of the Metropolitan Dade County Planning Department.

The persons interviewed had little idea of what precautionary costs for a hurricane in Dade County would be; nor did they know who might have this information.

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*Dade County and Miami, its major city, have a metro form of government.

Preliminary efforts were made in the other local study areas to obtain costs of preparing for hurricanes. It soon became apparent that such information is not readily available; therefore, it was decided to rely on the literature to estimate hurricane precautionary costs.

It has been estimated [18] that only 20 percent of the residents in a hurricane warning area take protective measures such as erecting storm shelters. A later study [19] argued that more credible warning would induce a larger percentage of the populace to take actions to inhibit storm damage. While this seems reasonable there is little knowledge available to quantify the variables involved. For example, if the overwarned area is reduced by 50 percent, how many more people would take precautions? With hurricane return rates running from seven to 16 years along the coastline, how long would it take for the populace in a given area to notice the improvement in warning effectiveness? It has been found that the experience of having been in a severe hurricane results in people paying more attention to warnings issued in the <u>near</u> future. For example, after the residents of Lower Cameron Parish, Louisiana, had been through Hurricane Audrey (1957), over 97 percent of them evacuated in accordance with the warning issued for Carla (1961) [20]. This was due not to an increased accuracy in the warning system, but to the fact that the same people had recently experienced a direct strike by a strong hurricane.

The only economic loss reduction mechanism that will be considered in this case study of improved hurricane forecasting will be that associated with the reduction of precautionary costs as the size of the warning zone is reduced.

In order to estimate the loss reductions, a number of assumptions will be made as listed below.

1. On the average, about one and one-half hurricanes strike the coastline being considered per year.

2. The number of totally false alarms, where a hurricane warning is issued and no hurricane-force winds touch the coastline, is small enough to be ignored (<<10 percent).

3. Population in the hurricane-affected areas is likely to grow between 10 percent and 30 percent by 1985.

4. Reduction in coastline overwarning will be a minimum of 10 percent and a maximum of 50 percent by 1985.

5. The cost of overwarning is directly proportional to population.

In estimating economic loss reductions, current dollar (1975) values will be used. Maximum and minimum values for pertinent variables will be estimated to calculate ranges. The basic economic data for overwarning costs have been taken from a classic paper written by Sugg [18].

The formula used to calculate the range of estimated loss reductions from reducing the overwarned area is

$$C_1 D_1 P_1 \leq B_W \leq C_2 D_2 P_2 \qquad (1)$$

where

C_1 and C_2 are low and high dollar values of the cost of overwarning per year [18], respectively, adjusted to 1975 dollar values, for 1.5 hurricanes per year.

D_1 and D_2 are low and high estimates of how much the overwarned areas may be decreased.

P_1 and P_2 are low and high projections of population growth until 1985 in the areas of interest.

B_W represents the annual loss reduction in 1975 dollars.

The 1966 costs of overwarning for 1.5 hurricanes per annum were projected to 1975 [18]. The minimum and maximum projected costs were, respectively, \$10,400,000 and \$34,900,000. An inflation factor of 20 percent was used in making this projection, however, this factor was more near 50 percent [22]. Modifying the numbers [18] to reflect the true effect of inflation leads to the following values of C_1 and C_2 to use in Equation (1):

$$C_1 = \$13,000,000$$

$$C_2 = \$43,600,000.$$

The 1975 population projections used [18] were accurate enough to need no revision. U.S. Department of Commerce data [23] was used to estimate 1985 population in the affected areas. It is estimated that growth between 1975 and 1985 in these areas is likely to be between 10 and 30 percent on the average, keeping in mind that the most vulnerable areas, those near the coastline may be even higher; thus, $P_1 = 1.1$ and $P_2 = 1.3$. Current forecasting methods are not likely to decrease the length of overwarned coastline included in a warning by more than 10 percent; thus, $D_1 = 0.1$. If the numerical models prove to be useful and better data gathering capability is brought to bear, it is possible that the overwarned area may be decreased by one-half, $D_2 = 0.5$. Using these values in Equation (1) yields estimated loss reductions from shrinkage of the warning zone to lie between $1,430,000 and $28,000.000 per year. The assumptions and results are summarized in Table 2.6.

2.4.5 Economic Loss Reductions Through Hurricane Modification

Conceivably, a hurricane could be modified to:

1. Change its path
2. Lower its peak winds and, therefore, diminish its destructiveness.

To date, there is no evidence that the path of a hurricane can be predictably altered so that it would miss land or strike in a less populated area. A theoretical-experimental base, however, does exist for decreasing its peak winds thereby, amel-

Table 2.6 Estimated Range of Cost Reduction Due to Improved Hurricane Forecasting - 1985

Parameter	Estimated Value	
	Minimum	Maximum
Cost of overwarning (millions of 1975 dollars)	$C_1 = 13$	$C_2 = 43.6$
Fraction by which overwarned area may be decreased	$D_1 = 0.1$	$D_2 = 0.5$
Ratio of coastal population in 1985 to current coastal population	$P_1 = 1.1$	$P_2 = 1.3$
Estimated minimum cost reduction	$= C_1D_1P_1$	= \$ 1.4 million
Estimated maximum cost reduction	$= C_2D_2P_2$	= \$28 million

iorating the destructive effects of both wind and storm surge. It has been shown [21] that the height of the hurricane-induced storm surge depends directly on the peak wind radius from the storm center and inversely on the pressure drop across the storm, among other factors.

The theoretical-experimental base is called hurricane modification, a technique of seeding hurricanes with silver iodide crystals, whose experimental results to date are promising but not proven.

Under Project Stormfury, a joint project of DOC and DOD, four Atlantic hurricanes have been seeded with indefinite results. Seeding of Hurricane Debbie (1969) produced

results compatible with expectations, a decrease in wind speed of 10-20 percent. The effect of seeding appears to last only about 24 hours. The first seeding reduced peak winds by 30 percent, the second seeding by 15 percent [13]. Practically continuous seeding to landfall may be required. Although theory would indicate a reduction in hurricane-induced surge, no significant reduction has been observed.

At the start of Project Stormfury, seeding of the inner eyewall clouds was considered to be most desirable. Since then, however, further understanding of hurricane dynamics and computer simulations of seeding experiments have revised this thinking. Currently, seeding outside the eyewall is expected to produce the most beneficial results. The simulations leading to this result were conducted on a two-dimensional model of a hurricane isolated from larger-scale atmospheric phenomena. Development and verification of a three-dimensional hurricane model embedded in a general circulation model will enable more realistic simulation of hurricane modification techniques, and will be a valuable tool in an integrated program of hurricane modification experimentation.

In 1972 DOD withdrew support from Project Stormfury; this action led to a 5-year hiatus in seeding experiments. Seeding flights are not expected to resume until 1977 when the project will be moved to the Pacific Ocean where there are more experimental targets since considerably more tropical cyclones occur in the Pacific than in the Atlantic.

The entire question of operational hurricane modification (as well as that of weather modification in general) has many unresolved political and legal questions. Currently, to avoid these questions, Project Stormfury has criteria to be met before a storm is seeded. One criterion is that no storm is seeded that is expected to reach land within 24 hours. Since the effects of seeding appear to be negated within a 24-hour period, this criterion will have to be modified before operational testing through landfall can be undertaken.

2.4.5.1 Case Study Results

The potential loss reduction resulting from hurricane modification will be derived employing the following assumptions:

1. Political and legal objections and obstructions to the use of hurricane modification techniques will be resolved to the extent required to make hurricane seeding an operational technique.

2. Project Stormfury will demonstrate that hurricane seeding is effective by 1985 and an operational program of hurricane seeding will be in use.

3. A maximum of 50 percent and a minimum of 10 percent of all hurricanes making landfall will be seeded.

4. Of those hurricanes seeded, the average decrease in peak winds will lie between 5 and 20 percent.

5. Damage caused by hurricanes can be allocated approximately 60 percent to storm surge and 40 percent to the effects of wind and rain [5 and 6].

6. Economic loss in the affected area is directly proportional to population.

7. Population in the hurricane-affected areas is likely to grow between 10 percent and 30 percent by 1985.

8. The influence of seeding on hurricane-induced storm surge will not be considered.

9. Economic loss is assumed to be directly proportional to wind force.

Suppose D is the annual damage resulting from all hurricanes that landfall. Then, from assumption (5) $0.4D$ is the annual damage resulting from wind and rain. Let P be the ratio of the population in coastal regions influenced relative to today's population in the same zone. Then, under assumption (6) the annual damage from wind and rain is $0.4DP$. Suppose that S is the fraction of all hurricanes that will be seeded from those that make landfall. Then, the damage associated with these hurricanes before seeding is $D_S = 0.4DPS$.

Seeding is assumed to reduce the peak winds of those hurricanes seeded. Let the ratio of the peak wind without seeding to the peak wind with seeding of a given hurricane be Q . Then the ratio of wind force without seeding to the wind force after seeding is Q^2 .

The damage associated with the seeded hurricanes, using assumption (9), is therefore $D_{SQ} = \frac{0.4DPS}{Q^2}$.

The loss reduction resulting from seeding, L_S , is therefore,

$$L_S = D_S - D_{SQ}$$

i.e.,
$$L_S = 0.4DPS\ [\ 1 - 1/Q^2\ ]$$

In the 1960s the damage produced by all hurricanes in the United States was estimated to be $450 million. From applying an inflation correction factor [22], the value of this damage in 1975 would be $675 million. Hence D = $675 million.

From assumption (7) by 1985 $1.1 \leq P \leq 1.3$. From assumption (3), $0.1 \leq S \leq 0.5$. From assumption (4) $\frac{1}{0.8} \geq Q \geq \frac{1}{0.95}$, therefore, $0.8 \leq Q \leq 0.95$.

The bounds of the loss reduction are then given in $ millions by

$$(0.1)(0.4 \times 675)(1.1)[1 - (0.95)^2] \leq L_S$$
$$\leq (0.4 \times 675)(1.3)[1 - (0.8)^2](0.5)$$

or

$$\$2.9 \text{ million} \leq L_S \leq \$63.2 \text{ million}.$$

2.4.6 Coastal Zone Economic Benefits

2.4.6.1 Benefits Related to Destructive Phenomena

Historical data has been examined to quantify the loss of life and the property damage resulting directly from the four principal natural phenomena which can be destructive in the United States coastal zones. Since the assignment of a dollar value to loss of life always is controversial, this loss will be excluded. Property losses were estimated to range annually from $146 million to $752 million in 1975. These property losses are some undefined mix of avoidable and nonavoidable losses. The avoidable losses being those which appropriate warning could mitigate, assuming that the population involved took every appropriate precautionary and preparatory action. What fraction of property losses are actually avoidable is evidently difficult to deduce. For a hurricane, it has been suggested that 60 percent of the damage results from the induced storm surge, 40 percent from wind and rain. It seems reasonable to assume that avoidable losses are more those that result from lack of control of the sea rather than the wind and the rain. Judgmentally, therefore, with proper capability to predict the sea's behavior, perhaps one-half of the losses associated with storm surge or 30 percent of the whole of the losses might be avoidable.

Tsunamis prediction is generally considered to be very good; it may therefore be reasonably argued that the tsunamis losses sustained are not avoidable. The losses resulting from surf and substantial breakers are perhaps 50 percent avoidable with adequate predictive knowledge and a capacity to implement the measures needed to endure the pounding generated by the breakers. The avoidable losses are the basis of benefits to the coastal zone. The economic losses of Table 2.4 are translated into benefits, as shown below, using the judgmental avoidable loss factors discussed in Table 2.7.

Table 2.7 Estimated Annual Maximum Benefits from Direct Action of Destructive Phenomena

	Total Property Loss Estimated $ millions			Avoidable Loss Factor	Estimated Maximum Benefits $ millions		
	Low	Average	High		Low	Average	High
Tropical Cyclones	50	200	500	0.3	15	60	150
Extratropical Storms	75	100	200	0.3	23	30	60
Tsunamis	0.5	1	1.5	0	0	0	0
Surf	20	26	50	0.5	10	13	25
Total	146	327	752		48	103	235

These benefits, by 1985, can be assumed to be dependent on relative population density in the coastal zone regions. The population factor can range from 1.1 to 1.3. Thus, in 1985 the maximum potential benefit related to direct action of destructive phenomena may range from $53 million to $306 million per annum.

2.4.6.2 Benefits Related to Hurricane Characteristics

Two additional cost reductions were attributed to better hurricane prediction and knowledge. A cost reduction range was determined, assuming that the predicted hurricane landfall would be improved. This cost reduction is in the expenditures needed to make preparation to prevent hurricane damage and loss of life. This cost reduction is therefore an avoidable loss directly related to improved prediction and is a distinct benefit additional to those resulting from the actual phenomena of the storm. These benefits in 1985 were estimated to range from $1.4 million to $28 million per annum.

Finally, hurricane modification was considered, the result of which is to reduce the amount of damage that can be produced by a hurricane. This is a prevention measure based on plausible theoretical physics but for which the experimental implementation technology remains unproven and undeveloped today. It is assumed, however, that by 1985 the seeding technique will reduce the losses produced by hurricanes and give rise to benefits which range from $2.9 million to $63 million, since hurricane seeding makes the losses avoidable.

The total annual benefits and the origins of these benefits are tabulated in Table 2.8.

The exact magnitude of the benefits that will be realized is difficult to assess. Prediction improvement clearly can generate benefits when economic losses can be avoided by a change in procedures according to what is predicted. That is, the change in procedure is itself the preventative measure.

Table 2.8 Coastal Zone Annual Benefits and Their Origins

Benefit Origin	Estimated Annual Benefit Range ($ millions)	
	Minimum	Maximum
Improved prediction of destructive phenomena produced sea conditions	53 *	306 *
Improved prediction of hurricane landfall	1.4	28
Effective seeding of hurricanes that will landfall	2.9	63
Total coastal zone benefits 1985	57	397

* These benefits require reduction by the cost and maintenance of the required prevention measures.

When naturally occurring phenomena have a destructive potential, knowledge and prediction of the occurrence of destructive characteristics of the phenomena implies the implementation of physical preventative measures with which a cost is associated. The cost of prevention and the maintenance of prevention reduces the essential annual benefit provided by knowledge and the capacity to predict the occurrence of destructive characteristics of the phenomena of importance. Both hurricane landfall prediction and effective hurricane seeding provide benefits that are from procedural changes. The benefits associated with direct losses from destructive phenomena imply some undefined additional preventative expenditures. With the assumptions of this case study, estimated annual benefits ranging from $4 million to $91 million seem, therefore, clearly acceptable but the possibility of achieving the full range of benefits from $57 million to $397 million seems doubtful or requires further study to generate the identity of the benefits.

2.4.6.3 Benefit Estimates Exclusive to SEASAT Data

The benefits derived will result from a wide variety of data and information only some part of which will come directly from SEASAT's operational instrumentation.

The SEASAT measurements of greatest interest to coastal zone phenomena prediction are:

- Surface winds

- Surface waves
- Atmospheric profiles of temperature and moisture
- Topography
- Surface temperature
- Sea ice

This is data which will feed into the many excellent numerical models that now exist. The following models all have application to this problem.

- Marine Wind Analysis Model (FNWC)
- Atmospheric Forecast Models with Boundary Layer Attachments (NOAA, FNWC, AFGWC)
- Ocean Circulation Model (Princeton/Bryan)
- Hydrodynamic Numerical Models (EPRF)
- Surface Current Analysis/Forecasting Models (EPRF, FNWC)
- Thermal Structure Analysis/Forecasting Models (FNWC, EPRF)
- Heat Exchange Models (EPRF)
- Spectral Wave Models (FNWC, EPRF, NYU, NAVOCEANO)
- Ocean Tidal Models (NOAA, EPRF)
- Dispersion/Diffusion Models for Pollutants (IPA, EPRF)
- Search and Rescue Models (USCG, EPRF, FNWC)
- Ocean Frontal Analysis/Prediction Models (NASA, FNWC)
- Acoustic Propagation Models (AESD)
- Storm Surge Models (NOAA, EPRF)
- Surf Prediction Models (NOAA, FNWC)

SEASAT will contribute data that will significantly improve data coverage in both space and time.

Tropical storms with the potential to become hurricanes are characterized by data collected from satellites and reconnaissance aircraft. These data are used at the National Hurricane Center (NHC) in Miami to predict the landfall using a number of prediction models [7 to 11]. Most techniques fit the current storm to historical storms and predict the present storm's position at various prediction intervals such as 24, 48 and 72 hours. "Statistical Prediction of the National Hurricane Center" [24] summarizes the various prediction techniques currently being used at NHC. A number of techniques are necessary since no single one of them is applicable to all hurricanes. The hurricane forecaster, after examining the predictions given by the different techniques, must exercise his experience and judgment to choose which output, or combination of outputs, to use as the forecast.

Significant improvement in landfall prediction will require operational dynamic simulations of hurricanes, for which a model is under development at the National Meteorological Center (NMC) at Camp Springs, Maryland.

Operational tests with actual hurricane data will be run on a 60 km grid model this summer as the first step in verifying its applicability to improving forecasting. Even if these tests are satisfactory, it will take an extended period of time to develop enough confidence in this, or any new, model for it to be used by the forecasters at NHC.

A 10 km model will then be embedded in the 60 km model and interact with it. The computational capacity to enable this level of simulation is not expected to be available for several years. In studying the data input problem, NMC has run computer experiments to determine solution sensitivity to the various required data [14] and accurate identification of the initial and three-dimensional wind field has been identified as the most important input requirement for the NMC 60 km grid model. The 10 km grid model will permit simulation of the hurricane eyewall and other small scale dynamics that are significant to the understanding of the hurricane seeding process.

Thus, development and verification of three-dimensional, numerical hurricane simulations will be invaluable to hurricane forecasting and investigation of hurricane modification, but these simulations will require large amounts of accurate input data for initialization. An operational SEASAT will be able to provide some of these data.

One of the best ways of showing how SEASAT would contribute to coastal zone phenomena prediction is through an influence matrix in terms of these major numerical models, which SEASAT would influence. Table 2.9 is a matrix showing the relative importance of the measurements to the numerical models.

Judgmentally, from this influence matrix and from familiarity with the computer models, it has been estimated that

Table 2.9 Model Influence for SEASAT Measurements

Model	SEASAT Measurement					
	Surface Winds	Surface Waves	Atmosphere Profiles	Topography	Surface Temperature	Sea Ice
Marine Wind Analysis Model	4	0	0	0	2	1
PE Atmospheric Forecast Model	3	2	4	0	3	1
Ocean Circulation Model	4	2	0	4	3	1
Hydrodynamic Numerical Models	4	0	0	3	0	1
Surface Current Models	4	3	0	4	3	1
Thermal Structure Models	1	3	0	2	4	1
Heat Exchange Models	4	0	3	0	4	0
Spectral Wave Models	4	4	3	0	1	1
Ocean Tidal Models	0	0	0	3	0	0
Dispersion/Diffusion Models	4	4	0	0	3	0
Search and Rescue Models	4	4	0	0	3	2
Ocean Front Models	3	1	0	3	4	0
Acoustic Propagation Models	0	4	0	0	4	2
Storm Surge Models	4	3	0	3	0	0
Surf Models	0	4	0			1

Code:
4 Critical Direct Influence
3 Major Direct Influence
2 Minor Direct Influence
1 Slight Direct Influence
0 No Influence

SEASAT would exclusively contribute 30 percent of the benefits that have been derived through its unique data contribution.

Tentatively, clearly acceptable coastal zone economic benefits <u>exclusive</u> to SEASAT are suggested to range from $1 million to $27 million annually, which the full range of benefits from $17 million to $119 million annually* seems doubtful without further study.

2.4.6.4 <u>Coastal Zone Benefits Generalized in Time</u>

Between 1985 and 2000, continued population growth in the coastal zones could be suggested but it is not clear that this will be the case at this time. It seems reasonable to assume that benefits derived will be realistic for each year from 1985 to 2000. The annual benefits resulting from this case study are tabulated in Table 2.10.

2.4.6.5 <u>Integrated Benefits</u>

The annual benefits of Table 2.10 will be integrated over the time interval 1985-2000 and will be discounted back from the end of the year of origin to the beginning of 1975 at different discount rates, using an integrated discount factor. The results are shown in Table 2.11.

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*This full range of SEASAT exclusive benefits refers to Table 2.8 which estimates the total coastal zone benefits in 1985 between $57 million to $397 million of which $17 million to $119 million represent the 30 percent of the total losses which may be avoidable.

Table 2.10 U.S. Coastal Zones Annual Benefit 1985-2000	
Benefit Origin	Annual range 1985-2000 $ millions
All data sources	4 - 91
Exclusive to SEASAT	1 - 27

Table 2.11 Coastal Zone Integrated Benefits				
Discount Interest Rate Factor	0% 16	5% 6.7073	10% 3.0162	15% 1.4716
Benefit range from all forecasting sources ($ millions)	64-1456	27-610	12-274	6-134
Benefit range exclusive to SEASAT date ($ millions)	16-432	7-181	3-81	1-40

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APPENDIX

A.1 Tropical Cyclones

North Atlantic Statistical and Coastal Zone Damage Summary

TOTAL NUMBER OF TROPICAL CYCLONES*			TOTAL NUMBER OF HURRICANES		LOSS OF LIFE		DAMAGE BY CATEGORY**	
YEAR	ALL AREAS	REACHING U.S. COAST	ALL AREAS	REACHING U.S. COAST	TOTAL ALL AREAS	UNITED STATES	TOTAL ALL AREAS	UNITED STATES
1931	9	2	2	0		0		#
1932	11	5	6	2		0		#
1933	21	7	9	5		63		7
1934	11	5	6	3		17		6
1935	6	2	5	2		414		7
1936	16	7	7	3		9		6
1937	9	4	3	0		0		4
1938	8	4	3	2		600		8
1939	5	3	3	1		3		3
1940	8	3	4	2		51		6
1941	6	4	4	2		10		7
1942	10	3	4	2	17	8	7	7
1943	10	4	5	1	19	16	7	7
1944	11	4	7	3	1076	64	8	8
1945	11	5	5	3	29	7	8	8
1946	6	4	3	1	5	0	7	7
1947	9	7	5	3	72	53	8	8
1948	9	4	6	3	24	3	7	7
1949	13	3	7	2	4	4	8	8
1950	13	4	11	3	27	19	7	7
1951	10	1	8	0	244	0	7	6
1952	7	2	6	1	16	3	6	6
1953	14	6	6	2	3	2	7	7
1954	11	4	8	3	720+	193	9	9
1955	12	5	9	3	1518+	218	9	9
1956	8	2	4	1	76	21	8	7
1957	8	5	3	1	475	395	8	8
1958	10	1	7	0	49	2	7	7
1959	11	7	7	3	57	24	7	7
1960	7	5	4	2	185	65	8	8

TOTAL NUMBER OF TROPICAL CYCLONES*			TOTAL NUMBER OF HURRICANES		LOSS OF LIFE		DAMAGE BY CATEGORY**	
YEAR	ALL AREAS	REACHING U.S. COAST	ALL AREAS	REACHING U.S. COAST	TOTAL ALL AREAS	UNITED STATES	TOTAL ALL AREAS	UNITED STATES
1961	11	3	8	1	345	46	8	8
1962	5	1	3	0	4	4	6	6
1963	9	1	7	1	7218+	11	9	7
1964	12	6	6	4	266	49	9	9
1965	6	2	4	1	76	75	9	9
1966	11	2	7	2	1040	54	8	7
1967	8	2	6	1	68	18	8	8
1968	7	3	4	1	11	9	7	7
1969	13	3	10	2	364	256	9	9
1970	7	4	3	1	74	11	9	8
1971	12	5	5	3	44	8	8	8
1972	4	3	3	1	128	121	9	9
1973	7	1	4	0	16	5	7	7
1974	7	1	4	1	3000+	1	8	8
TOTAL	419	159	241	78		2932		
MEAN	9.5	3.6	5.5	1.8		67		

**The Environmental Data Service has for some time recognized that, without detailed expert appraisal of damage, all figures published are merely approximations. Since errors in dollar estimates vary in proportion to the total damage, storms are placed in categories varying from 1 to 9 as follows:

1. Less than $50
2. $50 to $500
3. $500 to $5,000
4. $5,000 to $50,000
5. $50,000 to $500,000
6. $500,000 to $5,000,000
7. $5,000,000 to $50,000,000
8. $50,000,000 to $500,000,000
9. $500,000,000 to $5,000,000,000

* Including hurricanes.

Not reported in literature, believed minor.

+ Additional deaths for which figures are not available.

Damage Summary for Individual Tropical Storms and Hurricanes, Past 11 Years
(Atlantic and Gulf Coastal Zones)

DATE OF STORM	AREAS HARDEST HIT	MAXIMUM SUSTAINED WIND (KTS)	DAMAGE BY CATEGORY	REMARKS
1964				
Aug 7-8 *ABBY	Texas	60	5	Property damage due mainly to flooding. Matagorda, Tex. reported 39 kts, gusts to 56 kts.
Aug 20-Sept 4 CLEO	Florida to Virginia	122	8	Miami, Fla. estimated winds at 87-91 kts with gusts to 117 kts as center passed over area. Tides 4-6 ft above normal. Flooding caused heavy damage north to Va.
Sept 1-14 DORA	Florida, Georgia	108	8	Entered coast near Jacksonville, Fla. Tides 10-12 ft above normal. 71 kt wind recorded at Jacksonville, some miles inland. All major forces (wind, tides, flooding) caused extensive damage.
Sept 28-Oct 5 HILDA	Louisiana, Georgia, Carolinas	130	8	Over 100 kt winds hit La. coast east of Vermillion Bay. Franklin estimated 117 kts. 10 ft tides estimated near landfall. Over 2,600 dwellings demolished; all facilities offshore received heavy damage.
Oct 8-17 ISABEL	Florida to Virginia	78	7	Storm entered coast 47 mi NW of Miami which reported gusts 40-55 kts. Strong winds confined to small area. Tornados caused most damage.
1965				
Aug 27-Sept 12 BETSY	Southern Florida, Louisiana	130	9	Most destructive hurricane on record to date. 120 kt winds swept Fla. Keys, 130 kt winds hit La. coast. Tides of 7-9 ft above MSL hit Fla. Keys and La. coast. Heavy damage to shipping, oil facilities and installations due to wind and seas. $1.2 billion damage estimated in La.
Sept 24-30 *DEBBIE	Louisiana	45	7	Entered coast south of New Orleans and dissipated. Damage mainly due to flooding from heavy rains. Tides 2-4 ft above normal.

DATE OF STORM	AREAS HARDEST HIT	MAXIMUM SUSTAINED WIND (KTS)	DAMAGE BY CATEGORY	REMARKS
1966				
Jun 4-13 ALMA	Florida, Southern Georgia	125 (mph)	7	75 to 100 mph winds hit Fla. coast south of Tallahassee. Major damage due to tidal inundation and beach erosion. 6 lives lost in Fla.
Sept 21-Oct 11 INEZ	South Florida	140	7	South Fla. and Keys were main U.S. areas affected by storm which did extensive damage in Caribbean and Mexico. Homestead AFB reported gusts to 69 kts. Tides were 2-4 ft above normal in Fla. Keys.
1967				
Sept 5-22 BEULAH	Texas	130	8	Tex. received extensive crop, property damage due to flooding, strong winds. 15 deaths in Tex; 118 kt winds hit coast.
Sept 7-19 DORIA	New Jersey	99	-	Boating accident caused 3 deaths at Ocean City, N.J. Minor damage and beach erosion along mid-Atlantic states.
1968				
Jun 1-10 ABBY	Florida, Georgia, Carolinas	67	4	Jacksonville, Fla. recorded highest winds of any land station, 45 kts, gusts to 57 kts. Some damage due to flooding from heavy rains and tornado.
Jun 22-24 *CANDY	Texas	52	6	Tex. suffered bulk of damage with crop, property losses of $2.73 million. Strong winds, high tides caused extensive coastal damage. Gusts to 62 kts reported at San Antonio, Tex.
Oct 13-21 GLADYS	Florida	85	7	Tides of 3-7 ft along west coast of Fla.; strong winds caused major damage. Bayport, Fla. reported 73 kt winds. Damage in Fla. estimated $6.7 million.

DATE OF STORM	AREAS HARDEST HIT	MAXIMUM SUSTAINED WIND (KTS)	DAMAGE BY CATEGORY	REMARKS
1969				
Aug 5-22 CAMILLE	Mississippi, Louisiana, Virginia	175	9	Estimated winds of 175 kts; tides up to 24.2 ft above MSL demolished coastal towns near center as giant hurricane moved inland over Miss. 256 deaths in U.S.; $1.42 billion in damage. Serious flooding in Va.
Aug 21-Sept 10 GERDA	Florida, Maine	125	-	Coastal areas barely affected; only serious damage occurred where storm made landfall. Nantucket Lightship reported top winds 125 kts.
Oct 1-6 *JENNY	Florida	35	-	Wind gusts to 48 kts at Naples, Fla., no major damage.
1970				
May 17-27 ALMA	Florida, Georgia	70	-	Remnants of storm caused only minor wind damage over Ga. and S.C.
Jul 19-23 *BECKY	Florida	55	6	Damage to western Fla. due mainly to local flooding. 6 ft tides (3 ft above normal) reported at Panacea, Fla.
Jul 23-Aug 5 CELIA	Texas	113	8	Tides 9.2 and 9.0 ft above MSL recorded at Port Aransas Beach and Port Aransas jetty, respectively. 6 ft tides Corpus Christi to Galveston Bay. 85% damage confined to Corpus Christi area caused mainly by high winds. Peak gusts of 140 kts recorded at Corpus Christi. 48,316 Tex. families suffered losses.
Sept 11-17 *FELICE	Texas	60	-	Storm entered coast 26 mi NE of Galveston, Tex. Only minor damage as tides were 3.9 ft above normal at Cameron, La. Winds of 39 kts recorded at Galveston.

DATE OF STORM	AREAS HARDEST HIT	MAXIMUM SUSTAINED WIND (KTS)	DAMAGE BY CATEGORY	REMARKS
1971				
Aug 20-29 *DORIA	Virginia to Massachusetts	55	8	High surf battered some homes; swamped several small boats. Tides 2-4 ft above normal from Norfolk, Va. to Mass. Flooding, heavy rains accounted for most damage. 6 lives lost; 4 drowned along coast.
Sept 5-17 EDITH	Louisiana, Texas	140	7	Tides 5-8 ft above MSL recorded along La. coast; up to 6 ft at Sabine Pass; damage to crops biggest loss.
Sept 3-13 FERN	Texas	80	7	Heavy rainfall responsible for destructive floods. Tides 2-6 ft above MSL Port Arthur to Brownsville, Tex. 2 drowning deaths. Winds at Port O'Connor, Tex. 75 kts, gusts to 87 kts.
Sept 5-Oct 5 GINGER	North Carolina	90	7	Tides 2-4 ft above normal Norfolk, Va. to Morehead City, N.C. 4-7 ft tides on Pamlico Sound and estuaries. Damage to crops mainly from heavy rains. Wind gusts to 80 kts at Atlantic Beach, N.C.
1972				
Jun 14-22 AGNES	Florida to New York	75	9	One of worst natural disasters in U.S. history. Death toll 117, damage $3.1 billion. Highest tides in years did extensive damage in Fla, up to 7 ft at Cedar Key, Pa. Flooding accounted for 48 deaths.
Aug 29-Sept 5 *CARRIE	Massachusetts	60	6	Storm acted more like a northeaster. High waves caused erosion and swamped hundreds of small boats. 4 deaths; 2 in surf, 2 in boats. Gust of 73 kts reported at Pt. Judith, R.I.
1973				
Sept 1-7 *DELIA	Texas	60	7	Tides 5-7 ft above MSL caused severe flooding of Galveston, Tex. $3 million in damage to homes, $3 million to crops from heavy rain, flooding. 5 lives lost in Houston-Galveston area.

DATE OF STORM	AREAS HARDEST HIT	MAXIMUM SUSTAINED WIND (KTS)	DAMAGE BY CATEGORY	REMARKS
1974 Aug 29-Sept 10 CARMEN	Louisiana	130	8	Storm tides ranged up to 6 ft along the La. coast. Damage estimated at $90 million primarily to sugar cane crop; some damage to offshore oil installaions. Highest sustained wind measured over La. 75 kts.

*Tropical storm

A.2 Extratropical Storms

North Atlantic Coastal Damage
[Excerpted from Mariner's Weather Log (MWL)]

MWL Vol. 18, No. 2

December 17, 1973. A 988 mb low off Norfolk, Virginia moved north over Rhode Island. One of the worst storms in years to strike the east coast of the United States. Ice storm caused severe power outages. Utility companies called it the worst in 20 years. Thousands of homes were without light, heat and water.

MWL Vol. 18, No. 1, January 1974

August 20, 1973. A 28-foot cabin cruiser broke up and sank after hitting a jetty at Shinnecock Inlet on Long Island in heavy seas and fog. Waves at the mouth of the inlet were reported to be 8-10 feet from a low pressure center which developed rapidly off the Carolina coast.

MWL Vol. 17, No. 6, November 1973

June 9, 1973. A series of violent thunderstorms overturned hundreds of boats at Marblehead and Salem harbors, Massachusetts. Coast Guard cutters and helicopters pulled some 200 persons from the water.

MWL Vol. 17, No. 5, September 1973

March 21-24, 1973. A Cape Hatteras storm of 971 mb moved up the U.S. East Coast. The outer banks of North Carolina took a beating for three days. At least five motel units and two beach cottages were destroyed. A Norwegian freighter and a motor vessel sank in this storm; from crews of 30 and 29, there was only one survivor.

MWL Vol. 18, No. 4, July 1973

February 10-13, 1973. A low-pressure center formed 180 miles east of Charleston, South Carolina on February 10. For the next 36 hours, the storm devastated the coastal areas of North Carolina, South Carolina and Virginia. Winds of 55 knots and seas of

40 feet were reported at the time of high tide. Waves washed away huge sections of beach and destroyed or damaged many beach homes and business establishments. Roads were cut by washouts and high water;power was interrupted to many areas. North Carolina's outer banks were especially hard hit, with barrier dunes and beaches completely washed away. Damage totaled $4.1 million in insured losses alone.

MWL Vol. 17, No. 3, May 1973

November 15, 1972. A storm moved off the east coast after causing millions of dollars in damages in the Great Lakes area, (Michigan, $7.5 million and Ohio, $22 million) due to floods and wind.

December 4, 1972. The drogger Alton A and 44-foot Coast Guard utility boat were driven aground by heavy surf at the mouth of Casco Bay, Trundy Point, Maine. The Alton A, a wooden vessel, was holed and had to be salvaged.

MWL Vol. 17, No. 2, March 1973

September 21, 1972. A stationary low off Cape Hatteras generated heavy seas and strong winds which caused a barge under tow by the tug Carolyn to break loose and crash into the Chesapeake Bay Bridge connecting Cape Henry and Cape Charles. The bridge was knocked out in two places as 60-foot-long sections collapsed into the water. The bridge was closed to traffic for two weeks and the barge had to be removed and repaired. The tug had encountered 35 to 40 knot winds and 25 to 30-foot seas off Cincoteague before entering the Bay, where wind gusts of 50 knots were estimated.

MWL Vol. 17, No. 1, January 1973

October 6, 1972. A Cape Hatteras low moved north over Cape Cod causing more than usual damage along the coast. 35 to 40 knot gales and 51 foot seas swamped three small craft from Long Island to the Cape Cod area with loss of life. All were near the shore.

MWL Vol. 16, No. 4, July 1972

February 4, 1972. A storm was located off the New England coast with 64-knot winds. The 13,669 ton tanker Louisiana Getty ran aground at the entrance to Narragansett Bay. Storm tides were 3 feet or more

above normal as high surf caused damage to boats and coastal installations. Storm tides and high surf also battered lobster equipment and boats along the Maine coast. A boy was swept to his death by a breaker at Cape Elizabeth, Maine. Buildings were undermined by surf in Kittery to Portland area.

February 14, 1972. A storm moved through Pennsylvania and off the New England coast, causing abnormally high wind-driven tides in Chesapeake Bay area of Maryland, especially near Cambridge. High winds caused damage in New York City.

February 19-20, 1972. The most devastating storm in 75 years moved off the Maine coast and lashed New England north of the New Jersey coast with 55 to 60 knot gales. Big breakers pounded the coast for longer than usual during a northeaster. Massachusetts reported $40 million damages in the wake of the storm with 16 people injured. Damage was greatest along the coast where storm surge tides 2 to 4.5 feet above the normally high spring tides occurred with huge breakers and high surf. Flooded coastal homes included 400 from Revere, 300 each from Salem and Scituate; 27 houses destroyed, 3,000 damaged; sea walls and beaches were heavily damaged in Massachusetts. In Maine, 7 dwellings were destroyed, 600 damaged, sidewalks and roads were torn up and boats, wharves and lobster gear smashed. In New Hampshire, storm tides 2-4 feet above normal, high breakers and surf damaged over 100 homes and buildings, washed out roads, sidewalks and devastated beaches and coastal installations.

MWL Vol. 16, No. 3, May 1972

December 18, 1971. A rapidly developing storm off North Carolina coast with 50-knot winds sank a tugboat in Albemarle Sound; 6 persons were lost. A 9,165-ton Liberian cargo ship went aground at Old Point Comfort, Virginia; a barge with 14,500 barrels of crude oil grounded on a shoal near the mouth of the Potomac River; a 55-foot yacht foundered in shallow water off Pamlico Sound; another 55-foot yacht sank near Hobucken, south of Pamlico Sound and a 26-foot cabin cruiser was driven aground at Fort Story.

MWL Vol. 16, No. 2, March 1972

October 10, 1971. A low-pressure center over Maryland moved north to Quebec. Several small craft

were in trouble along the North Carolina coast where two were found adrift with all personnel lost.

MWL Vol. 15, No. 5, September 1971

March 2-7, 1971. A major cyclone developed over Mexico, moved across the southeastern United States and up coast as a 963 mb low over Portland, Maine (a record for that area). A natural gas rig sprung several leaks south of Lake Charles, Louisiana; a tug sank while towing two barges off the Mississippi coast; a supply vessel broke the anchor chain and sank near New Orleans. A British freighter was torn from its moorings at Baltimore, Maryland, inflicting severe damage to the ship and a pier. A Greek vessel dragged anchor and struck bridge abutments in Narragansett Bay. High winds and 51-foot seas were reported off the New England coast during the storm.

March 26-28, 1971. The second northeaster of the month produced the highest water levels at Norfolk, Virginia, since the Ash Wednesday storm of 1962. The storm produced 65-knot winds at Diamond Shoals, as gale warnings were displayed from Florida to New England. The seawall which protects up to ten feet above the mean low water park prevented 2-3 feet of water in the streets of downtown Norfolk on March 26. The tide crested 2.8 feet above normal at Norfolk and 3.9 feet above normal at Virginia Beach. The fishing pier at Virginia Beach was washed away, along with the tide gauge. Low coastal areas were flooded. A 175-foot barge sank in Hampton Roads and a tanker sank off Cape Hatteras with 220,000 barrels of fuel oil aboard. Only 13 of the 44-man crew were rescued.

April 5-8, 1971. A Gulf of Mexico wave moved northeast and deepened rapidly off Cape Hatteras. Martha's Vineyard recorded gusts to 68 knots. Tides as much as 4 feet above normal, rough seas and breakers superimposed on the high tide caused considerable flooding and beach erosion from New Jersey to the Virginia Capes.

MWL Vol. 15, No. 4, July, 1974

February 8-9, 1971. A low developed over the Gulf of Mexico with 65-knot winds at Vera Cruz, Mexico. Gale and storm tide warnings were issued for the Atlantic Coast from New Jersey to Connecticut. As the cold front from this system pushed through Florida, gusts

MWL Vol. 15, No. 3, May 1971

December 26-27, 1970. Explosive deepening of a storm off Cape Hatteras (over 25 mb in 12 hours - 50 mb in 24 hours) generated 50 to 65 knot winds and high seas. The 12,155 ton Norwegian oil tanker Bente Brovig and the 13,080-ton Brazilian vessel Docelago dragged anchors, colliding at Hampton Roads, Virginia. Two other ships sank at sea with at least 22 lives lost during the storm.

North Pacific Coastal Damage
[Excerpted from Mariners Weather Log (MWL)]

MWL Vol. 18, No. 2, March 1974

January 17, 1974. A 68-foot fishing vessel capsized off the Golden Gate Bridge in turbulent seas.

MWL Vol. 17, No. 5, September 1973

April 1, 1973. Southern California was swept by high winds from a low over the Great Basin and a high off the Pacific Coast which created 12-foot seas and 35 to 40 knot gales from San Francisco to Baja, California. An 80-ft. boat was capsized by wind and swell off San Diego.

MWL Vol. 17, No. 3, May 1973

December 24, 1972. A 48-foot crab boat was overturned three times by huge swells off the northern California coast; four men were rescued.

MWL Vol. 16, No. 6, November 1972

August 17-18, 1972. A low-pressure center about 200 miles off the Pacific Northwest caused wind gusts up to 65 knots and 14-foot seas. Some 30-40 sport and fishing boats were destroyed between Eureka, California and Brookings, Oregon. Winds ripped off roofs, toppled trees and cut electric power in coastal communities. The death toll was 13.

MWL Vol. 15, No. 5, September 1971

March 12, 1971. A 959 mb low off the Pacific Northwest produced 60-knot gusts and 26-foot swells. The tug Go Getter was caught off Cape Blanco, Oregon. The tug was damaged and had to be rescued by the Coast Guard.

MWL Vol. 15, No. 4, July 1971

January 13-15, 1971. A 964 mb low-pressure center off the Pacific Northwest brought wind gusts of 80 to 100 knots to the Oregon coast causing $2.8 million in damage, mainly to homes, buildings, timber and livestock. A tug had to drop tow of 800 tons of pulp and take shelter 15 miles east of Victoria, B.C.

January 9, 1971. The 8,101-ton Italian ship Galileo Farraris collided with Pier 37 at Seattle, Washington. As high winds swung the ship into the pier, a 190-ton crane on the pier was toppled into the water.

MWL Vol. 14, No 6, November 1970

May 17, 1970. The Aristides Xilas, a Greek vessel, left San Francisco but, due to gusty winds behind a cold front, the deck lashing broke, cargo shifted and hatches opened. The ship was forced to return to San Francisco at reduced speed.

MWL Vol. 14, No. 5, September 1970

March 1970. Early in March, the 5,886-ton Canadian barge Island Importer was blown against the west pier of the Burnside Street Bridge while being guided down the Willamette River at Portland, Oregon. Damage to the pier was estimated at $10,000:

April 13-14 1970. Northwesterly gale-force winds blowing along the California coast caused the 7,114-ton Panamanian freighter La Janelle to break from

anchorage and go aground west of the entrance of Port Hueneme, California. The vessel was awash on her side.

MWL Vol. 14, No. 3, May 1970

November 4, 1969. Gales raked the Pacific Coast north of Point Arena, California, just before the low-pressure center moved inland at Vancouver. Winds gusted to greater than 60 knots at Cape Blanco, Oregon. Breakers were estimated at 35-40 feet in some places. Wave damage was minimal because the astronomical tide was low during the storm period.

MWL Vol. 13, No. 4, July 1969

February 5-6, 1969. Two energetic cold fronts passed through California during this period. The second front, an occlusion, was the strongest. Early on 6 February, seas as high as 44 feet and winds of 45 knots were reported west of Point Arena. Damage was reported in the vicinity of the coast between San Francisco and San Diego but particularly heavy losses were reported near Santa Rosa and Redwood City.

MWL Vol. 19, No. 1, January 1975. Monterey Peninsula Herald, November 13, 1974.

November 12, 1974. Winds of 60 knots battered the western Alaska coast from a low over the Bering Strait. Waves breached the sea wall and flooded areas of Nome to a depth of 5 feet and pushed sea water into at least six other coastal communities. Some buildings were destroyed and numerous persons forced from their homes. Half of the city of Nome was without electric power; the sewage system was out and the water supply suspect. Two main streets were flooded. Other villages reported collapsing sea walls and widespread flooding. Governor William A. Egan termed the devastation a "fullscale disaster" and called on President Ford to supply federal disaster assistance funds for the coastal communities.

MWL Vol 14, No. 4, July 1970

January 14, 1970. A strong cold front struck Hawaii, resulting in the greatest dollar damage ($6.84 million) ever reported for that state for a single weather event. There was $4.48 million in damage to the army barracks on Oahu alone. Wind gusts to 83 knots were reported.

A.3 Tsunamis

Although tsunamis, seismic sea waves, occasionally cause severe damage in coastal zones (particularly around the Pacific basin), the warning system now in being is considered to be very good.

Pararas-Carayannis* has published a Catalog of Tsunamis in the Hawaiian Islands which indicates that the islands have been struck by eight-five seismic sea waves in the last century and a half. These tsunamis caused at least 383 deaths and damage estimated at $57,000,000. Because of its harbor configuration, Hilo has suffered more damage than any other Hawaiian city. Major seismic waves damaged Hilo in 1837, 1868, 1946 and 1960.

Cox** reports that Alaska has experienced forty tsunamis in 181 years. The Scotch Cap Tsunami, which claimed 79 lives, is the most famous case in recent years. Various West Coast areas of the United States have suffered some damage from seismic sea waves, but no good economic summaries could be found. However, Bascom*** states that Los Angeles and San Diego harbors suffered a million dollars worth of damage to piers and small craft during the 1960 tsunami.

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* Pararas-Caroyannis, G., A Catalogue of Tsunamis in the Hawaiian Islands, Environmental Science Service Administration, Honolulu, Hawaii.

** Cox, D. C. and G. Pararas-Caroyannis, Catalogue of Tsunamis in Alaska, Environmental Science Service Administration, Honolulu, Hawaii.

*** Bascom, W., Waves and Beaches, Science Study Series, Doubleday and Company, Inc., New York, 1964, pp 267.

A.4 Surf

Pacific Coast and Hawaiian Islands Damage Reports
[Excerpted Mariner's Weather Log (MWL)]

MWL Vol. 14, No. 3, May 1970

December 4-6, 1969. The two huge Pacific storms that caused the tremendous waves over the Hawaiian Islands the first part of December 1969 directed their energy toward the Southern California coast on December 4th and 6th. The first swells averaged 5 to 8 feet with an occasional 10-footer arriving off the Southern California Coast early on December 4th. Directly exposed beach areas were pounded by 12-14 foot breakers with the more sheltered areas reporting breakers in the 4-8 foot range. Because the breakers arrived on slightly above normal high tides, beach damage consisted mainly of weakened and undermined sea walls. Many tons of protective sand were transported away from low-lying beach areas. A heavy spray washed over and closed the 25-foot pier at Ocean Beach. There were 9-foot waves at beaches from Oceanside to Del Mar, and in South Carlsbad water swept into a parking lot that is normally 10 feet above high tide. The Ventura Pier was damaged by 20-foot waves and closed until damage could be fully assessed. An undetermined number of pilings were broken. Two young men were missing off Santa Barbara when their 14-foot skiff was swamped a short distance from a larger boat

they were trying to reach.

Swells of 8-10 feet with 10 to 18-foot breakers were forecast to reach Southern California beaches early on December 6th from the second storm. Disaster and property protection agencies quickly mobilized men and equipment to meet this heavy onslaught. Arriving on spring tides some 4 feet above normal high tide, the situation was quite critical for many beach areas already vulnerable because of damage inflicted only 48 hours earlier. Swells of 8-10 feet with some near 12 feet and breakers 12-20 feet hammered away at exposed beaches through December 6th. Some of the giant breakers overtopped the 20-foot seawall at Redondo Beach and 15-foot breakers rolled under the Redondo Beach Pier. Heavy seas were listed as the contributing factor to the loss of 4 lives during the period while property damage was estimated near $1.5 million. Several beach homes were destroyed, 30 more were flooded and over 100 others were evacuated. A possible greater loss of life and property would have occurred had it not been for the efforts of disaster agencies and volunteer workers who hastily repaired sand dikes and replaced sand bag barriers which were constantly being destroyed by the raging seas.

MWL Vol. 14, No. 3, May 1970

December 12-14, 1969. A 963 mb low moved into the eastern North Pacific and then north toward Alaska with 55-knot winds and 33-foot seas. Waves up to 24-feet pounded the municipal fishing pier at Ocean Beach, California on December 14th. Four lives were lost and more than $1 million damage was reported to Southern California beach areas. At Ensenada, Mexico, fishermen reported more than 100 small boats and 4,000 lobster traps destroyed.

December 15-20, 1969. A 956 mb low moved east toward the California Coast, then changed direction and moved northwest toward Alaska. The low held about 956 mb for 36 hours, having combined with a second low-pressure center. Winds near hurricane force spawned huge waves that lashed beachfront homes at Oxnard, California on December 19th. The storm sank a Navy patrol boat and beached another.

MWL Vol. 13, No. 4, July 1969

January 18-26, 1969. A vast area of low pressure over the eastern Pacific spawned a succession of low-pressure centers that lashed the California coastline for nine

straight days. Six frontal systems passed over Southern California. These fronts brought high winds (50 to 60 knots) and very heavy rain to coastal areas of the state and to vessels in offshore waters. An estimated $125 million damage occurred in seven counties adjoining the Los Angeles area. At least 45 deaths are directly attributed to the storm. A number of principal highways and some mainline railroads were closed by flooding or mud slides and utilities were disrupted in many areas. At least 9,000 persons were evacuated to safety. Wind damage to marinas and boats occurred in several areas. Sherman Island, a dike-protected agricultural area of more than 10,000 acres, was covered with up to 20 feet of water where a section of the dike gave way. The passage of ocean vessels to inland ports was curtailed for several days as a protection to other storm-weakened dikes in the delta.

MWL Vol. 18, No. 2, March 1974

January 7, 1974. A monster surf pounded the north shore of Oahu at popular surfing site Waimea Bay. An intense winter storm midway between Hawaii and the Aleutians produced waves of 35 feet which resulted in 18-foot waves on the north shore of Oahu. These waves caused widespread damage throughout the Hawaiian Islands.

MWL Vol. 17, No. 1, January 1973

August 18, 1972. Waves generated by hurricane DIANA created heavy surf greater than 25 feet which pounded the southeast coast of Hawaii. At Kapoho Beach, damage to four homes was estimated at $70,000.

MWL Vol. 15, No. 3, May 1971

November 24, 1970. Long fetch area on the east side of a Pacific high-pressure area with northerly winds created waves to 25 feet along the north coast of the Hawaiian Islands. Many homes and roads were inundated and a major inter-island harbor was closed.

MWL Vol. 14, No. 3, May 1970

December 20, 1969. Complex low-pressure systems over the eastern North Pacific spawned winds near hurricane force. The cold front from this storm passed Kauai and Oahu on December 20th. High surf drove more than 100 persons from their homes as an alert was issued for all of Hawaii. Families were evacuated from homes on the north

shore of Oahu and Red Cross shelters were mobilized. The surf caused the closing of roads at many points on the island.

December 1, 1969. An intense storm which developed in the western Pacific on November 29th moved east at relatively low latitudes before turning toward the Gulf of Alaska. Gale force winds over a 900-mile fetch built monstrous seas directed at the Hawaiian Islands. Ship reports in the fetch area reported 55-knot northwesterly winds and 35-foot seas. Decaying only slightly, these waves pounded the Hawaiian Island chain with 30 to 40-foot breakers on December 1st. Later on the 2nd, tremendous waves, rising up to 50 feet in some places, slammed into a 10-mile stretch of the north shore of Oahu. Two persons were reported missing and a third man died of a heart attack, while fifteen persons were slightly injured. The heavy surf necessitated the evacuation of more than 1,000 people from their homes. One giant wave rolled over a house standing 26 feet above sea level and left seaweed on its roof. Other homes were pushed off their foundations and left standing in roadways. Officials estimated that at least 34 homes were destroyed, and property damage was estimated at more than $1 million.

December 4-5, 1969. Another huge storm with a history of 60-knot winds rolled across the Pacific in the wake of the December 1-2 storm. The cold front reached Kauai at about 1200Z on December 4th. During the next 24 hours, it penetrated all the Hawaiian Islands except the big island of Hawaii, and caused 40-foot surf. The number of home evacuees increased from more than 1,000 from the previous storm to 2,000 persons.

A.5 Coastal Monterey, California USCG Calls For Assistance - 1974 Records

The records were frequently incomplete as to property damage estimates or property values in particular cases, but contain sufficient information to indicate the magnitude of property lost or damaged for a specific area which may be applied to estimates for larger areas.

Month	Summary of Most Significant Events (Calls for Assistance)	Weather Conditions
JAN 74	50-ft. sailboat ($30,000 property) 7 miles west of Point Sur taking on water. 3 persons on board. Machinery problems complicated by weather. USCG towed vessel to Monterey. No damage estimate.	WIND: NW 35 KTS SEAS: NW 18 FT VIS: 4 miles
	15-ft. outboard ($1,000 property) 20 yards off-shore near Hopkins Marine Station capsized and smashed against the rocks. Two persons on board. 1 fatality. 1 survivor. Boat was total loss. Large swell passed under boat while passengers engaged in fishing.	WIND: N 10-15 KTS SEAS: 2-4 FT Moderate surf

Month	Summary of Most Significant Events	Weather Conditions
JAN 74	Total calls for assistance: 11 Known damage: $1,000 Fatalities: 1	
FEB 74	6-ft rubber raft ($100 property) adrift 50 yards offshore unable to make headway with oars. Surf too rough. 2 persons onboard. USCG towed raft to safety.	WIND: NE 6 KTS SEAS: 1-2 FT VIS: 15 miles
	20-ft. sailboat ($5,000 property) dragging anchor, possibly caught under the wharf. USCG removed vessel. None on board. No damage estimate.	WIND: NNE 18 KTS SEAS: 2 FT VIS: Unlimited
	32-ft fishing boat ($5,000 property) ran aground; broke up on rocks off Yankee Point and sank as it was destroyed by the surf. 1 person onboard rescued from water by Army helicopter. Boat was total loss.	WIND: 6 KTS SEAS: 5-7 FT
	10-ft sailboat ($300 property) with broken mast 200 yards offshore. 2 persons onboard. USCG towed vessel to safety. No damage estimate.	WIND: NW 18 KTS SEAS: 3-4 FT
	25-ft inboard boat ($2,500 property) ran aground in Moss Landing Channel. 5 persons onboard. Refloated by USCG and towed to safety. No damage estimate.	WIND: WNW 24 KTS SEAS: 9-10 FT
	18-ft fishing troller broke mooring 1/3 mile offshore. None onboard. USCG towed vessel to safety. No damage estimate.	WIND: WNW 21 KTS SEAS: 3 FT
	Total calls for assistance: 20 Known damage: $5,000 Fatalities: 0	

Month	Summary of Most Significant Events	Weather Conditions
MAR 74	18-ft sailboat capsized 1 mile offshore with broken mast. Towed to safety by private vessel. No damage estimate.	WIND: SW 15 KTS SEAS: 2-3 FT
	26-ft sailboat ($8,000 property) dragging anchor 1/4 mile offshore. None aboard. USCG safely moored vessel. No damage.	WIND: WNW 20 KTS SEAS: 3-4 FT
	24-ft cabin cruiser ($7,500 property) disabled 1/2 mile offshore. 4 persons onboard. USCG towed vessel to Santa Cruz. No damage estimate.	WIND: S 20 KTS SEAS: 5-6 FT
	26-ft pleasure boat ($5,000 property) ran aground 100 yards east of Santa Cruz. 3 persons onboard. People got ashore. USCG unable to pull boat to safety. Vessel was reported to be breaking up in surf. Owner seeking commercial assistance. Final damage and disposal unknown.	WIND: S 2 KTS SEAS: 3-4 FT High Surf SKY: OVC/FOG VIS: 1/4 mile
	14-ft sailboat ($600 property) capsized 1-1/4 miles off Santa Cruz. 3 persons onboard. 2 drowned, 1 rescued but later died. Boat was lost.	WIND: SE 10 KTS SEAS: 2 FT SKY: Overcast VIS: 8 miles
	Swimmer in trouble 50 yards offshore at Carmel Point. Person drowned.	WIND: NW 14 KTS SEAS: 5-6 FT
	14-ft inboard/outboard ($3,500 property) adrift 300 yards off Point Pinos. Engine failed as boat was dangerously near the rocks. 2 persons onboard. USCG reached vessel in time and towed to safety. No damage.	WIND: NW 14 KTS SEAS: 8-10 FT SKY: Clear VIS: 20 miles
	Total calls for assistance: 27 Known damage: $600 Fatalities: 4	

Month	Summary of Most Significant Events	Weather Conditions
APR 74	30-ft commercial fishing boat ($30,000 property) ran aground 200 yards off Pt. Pinos; broken up on rocks by surf. 4 persons onboard. Rescued by Army helicopter and treated at Monterey Hospital. Boat was destroyed.	WIND: NW 12 KTS SEAS: 5-6 FT
	Commercial fishing boat was demasted 5 miles offshore. USCG towed boat to safety. No damage estimate given.	WIND: NW 12 KTS SEAS: 6-8 FT
	33-ft commercial fishing boat ($100,000 property) was disabled 2 miles offshore with broken fuel line. USCG towed vessel to Moss Landing and safety.	WIND: W 14 KTS SEAS: 6-7 FT
	18-ft sailboat capsized off Santa Cruz; boat righted itself and made harbor safely. No damage estimate.	WIND: NW 27 KTS SEAS: 4-5 FT
	20-ft sailboat capsized near Santa Cruz. 2 persons onboard. 1 rescued; 1 missing. No damage estimate.	WIND: NW 27 KTS SEAS: 4-5 FT
	Total calls for assistance: 26 Known damage: $30,000 Fatalities: 1	
MAY 74	16-ft trimaran ($1,600 property) capsized 1 mile SE of Santa Cruz.	WIND: W 30-35 KTS SEAS: 6-8 FT
	18-ft catamaran ($2,000 property) capsized 1-1/2 miles south of Santa Cruz. 3 persons onboard. USCG towed vessel to safety at Santa Cruz.	WIND: 30-40 KTS SEAS: 3-4 FT
	Total calls for assistance: 38 Known damage: none Fatalities: 0	

Month	Summary of Most Significant Events	Weather Conditions
JUN 74	23-ft Inboard/outboard boat ($10,000 property) in the surf 3 miles south of Moss Landing. 2 persons onboard.	WIND: SW 10 KTS SEAS: Surf 4 FT
	20-ft catamaran ($6,000 property) 1 mile offshore. None onboard. Towed to safety by USCG.	WIND: 22 KTS SEAS: 1-2 FT
	Total calls for assistance: 24 Known damage: none Fatalities: 0	
JUL 74	18-ft inboard/outboard (4,000 property) dragging anchor 1/8 mile offshore. USCG moored vessel safely.	WIND: NW 18 KTS SEAS: 1-2 FT
	4 other small boats broke moorings. All were retrieved by USCG. No damage.	WIND: 10-15 KTS SEAS: 1-3 FT VIS: Good
	Total calls for assistance: 21 Known damage: none Fatalities: 0	
AUG 74	Fishing boat ($60,000 property) on rocks near Pt. Sur. 3 persons onboard, rescued. Boat not salvageable (total loss).	WIND: Calm SEAS: Heavy breakers SKY: Obscured/fog
	Total calls for assistance: 17 Known damage: $60,000 Fatalities: 0	
SEPT 74	25-ft Sea Scout vessel adrift in danger of breaking up. 5 persons onboard. USCG towed vessel to safety.	WIND: NW 14 KTS SEAS: 3-4 FT
	14-ft sailboat offshore overturned, adrift and demasted. 1 person onboard, rescued. Small damage.	WIND: 4 KTS SEAS: 2-3 FT
	Total calls for assistance: 24 Known damage: none Fatalities: 0	

Month	Summary of Most Significant Events	Weather Conditions
OCT 74	70-ft fishing boat dragging anchor 1/4 mile offshore. None onboard. USCG safely moored vessel.	WIND: 25 KTS SEAS: 4-5 FT
	18-ft outboard boat dragging anchor 1/2 mile offshore. USCG towed vessel to safety, Monterey Marina.	WIND: 28 KTS SEAS: 6-7 FT SKY: OVC/RAIN VIS: 6 miles
	20-ft inboard boat broke moorings 1/4 mile offshore. Picked up by another vessel.	WIND: 28 KTS SEAS: 6-8 FT SKY: OVC/RAIN VIS: 6 miles
	30-ft fishing boat dragging anchor 1/4 mile offshore. USCG towed vessel to safety at Monterey.	WIND: 28 KTS SEAS: 9-10 FT SKY: OVC VIS: 10 miles
	35-ft fishing boat dragging anchor 1/4 mile offshore. Safely moored to another vessel by USCG.	WIND: 28 KTS SEAS: 9-10 FT SKY: OVC
	20-ft sailboat and 18-ft sailboat dragging anchor 1/8 mile offshore. USCG safely moored both vessels to buoy.	WIND: 15 KTS SEAS: 3-5 FT VIS: 12 miles
	19-ft outboard ($5,000 property) disabled and ran aground. USCG unable to tow boat through surf. All persons on board safely on shore. Owner received commercial assistance. No damage estimate.	WIND: 15 KTS SEAS: 5-7 FT SKY: OVC VIS: 10 miles
	Total calls for assistance: 40 Known damage: none Fatalities: 0	
NOV 74	Several boats were driven ashore by an overnight storm. One was an approximately 40-ft. fishing boat with full cargo of fish which was a total loss. Property damage and loss estimated at $137,000.	Unknown

Month	Summary of Most Significant Events	Weather Conditions
	Total calls for assistance: 16 Known damage: $137,000 Fatalities: 0	
DEC 74	42- ft. fishing boat ($35,000 property) disabled with engine failure 1-1/2 miles offshore. USCG towed to safety. No damage.	WIND: ESE 25 KTS SEAS: 6-7 FT
	22-ft sailboat ($4,000 property) dragging anchor 50 yards offshore. USCG towed boat to safety. No damage.	WIND: 20 KTS SEAS: 3 FT
	4 boats, 18- and 26-ft., moored to a raft, dragging anchor 50 yards offshore. USCG safely moored boats to a buoy. No damage.	WIND: 25 KTS Gust to 30 KTS SEAS: 7-8 FT SKY: OVC VIS: 5 miles
	2 boats on rocks. 1 broke up and sank. One, a 40-ft launch, was towed to safety by USCG. No estimate except moderate damage to launch. 1 other fishing boat destroyed in surf. Damage unknown.	WIND: 25 KTS SEAS: 7-8 FT SKY: OVC VIS: 5 miles
	Total calls for assistance: 10 Known damage: 1 boat sank; 1 boat destroyed in surf Fatalities: 0	
ANNUAL TOTAL	Calls for assistance: 274 Known damage: $233,600 + Fatalities: 6	

A.6 Hurricane Phenomena

*Hurricane Disaster-Potential Scale:

The hurricane disaster-potential scale is an experimental effort by the National Weather Service to give public safety officials a continuing assessment of the potential for wind and storm-surge damage from a hurricane after it reaches a point where it could be a threat to their coastal populations.

Scale numbers are made available to public-safety officials when a hurricane is within 72 hours of landfall.

Scale numbers range from 1 to 5—with Scale No. 1 having at least the threshold windspeed of a hurricane of 74 miles per hour, or a storm surge 4 to 5 feet above normal water level—and Scale No. 5 having a windspeed of 155 miles per hour or more, or a storm surge more than 18 feet above normal.

The Weather Service emphasizes that the disaster-potential numbers are not forecasts, but will be based on observed conditions at a given time in a hurricane's lifespan. They represent an estimate of what the storm would do to a coastal area if it were to strike without change in destructive power. Scale assessments will be revised regularly as new observations are made, and public-safety organizations will be continually advised of new estimates of the hurricane's disaster potential.

The Disaster-Potential Scale gives probable property damage and evacuation recommendations as follows:

Scale No. 1—Winds of 74 to 95 miles per hour. Damage primarily to shrubbery, trees, foliage and unanchored mobile homes. No real damage to other structures. Some damage to poorly constructed signs. Or: storm surge 4 to 5 feet above normal. Low-lying coastal roads inundated, minor pier damage, some small craft in exposed anchorages torn from moorings.

Scale No. 2—Winds of 96 to 110 miles per hour. Considerable damage to shrubbery and tree foliage, some trees blown down. Major damage to exposed mobile homes. Extensive damage to poorly constructed signs. Some damage to roofing materials of buildings; some window and door damage. No major damage to buildings. Or: storm surge 6 to 8 feet above normal. Coastal roads and low-lying escape routes inland cut by rising water 2 to 4 hours before arrival of hurricane center. Considerable damage to piers. Marinas flooded. Small craft in unprotected anchorages torn from moorings. Evacuation of some shoreline residences and low-lying island areas required.

Scale No. 3—Winds of 111 to 130 miles per hour. Foliage torn from trees, large trees blown down. Practically all poorly constructed signs blown down. Some damage to roofing materials of buildings; some window and door damage. Some structural damage to small buildings. Mobile homes destroyed. Or: storm surge 9 to 12 feet above normal. Serious flooding at coast and many smaller structures

Definition of the Scale

Category	Central Pressure (millibars)	Winds (mph)	Surge (ft)	Example
1	>980	74-95	4-5	Agnes 1972 (Fla. coast)
2	965-979	96-110	6-8	Cleo 1964
3	945-964	111-130	9-12	Betsy 1965
4	920-944	131-155	13-18	Donna 1960 Fla., Carla 1961 Tex.
5	<920	>155	>18	1935 Storm on Fla. Keys

*Developed by Herbert Saffir, Dade County consulting engineer.

near coast destroyed; larger structures near coast damaged by battering waves and floating debris. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives. Flat terrain 5 feet or less above sea level flooded inland 8 miles or more. Evacuation of low-lying residences within several blocks of shoreline possibly required.

Scale No. 4—Winds of 131 to 155 miles per hour. Shrubs and trees blown down, all signs down. Extensive damage to roofing materials, windows and doors. Complete failure of roofs on many small residences Complete destruction of mobile homes. Or: storm surge 13 to 18 feet above normal. Flat terrain 10 feet or less above sea level flooded inland as far as 6 miles. Major damage to lower floors of structures near shore due to flooding and battering by waves and floating debris. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives. Major erosion of beaches. Massive evacuation of all residences within 500 yards of shore possibly required, and of single-story residences on low ground within 2 miles of shore.

Scale No. 5—Winds greater than 155 miles per hour. Shrubs and trees blown down, considerable damage to roofs of buildings; all signs down. Very severe and extensive damage to windows and doors. Complete failure of roofs on many residences and industrial buildings. Extensive shattering of glass in windows and doors. Some complete building failures. Small buildings overturned or blown away. Complete destruction of mobile homes. Or: storm surge greater than 18 feet above normal. Major damage to lower floors of all structures less than 15 feet above sea level within 500 yards of shore. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives. Massive evacuation of residential areas on low ground within 5 to 10 miles of shore possibly required.